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Dissertation

AN INTERFEROMETER METHOD OF DETERMINING
WAVE LENGTHS IN THE HYDROGEN SPECTRUM

by

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(B.S, Wesleyan University, 1921; A.M., Boston University, 1928)

submitted in partial fulfilment of the
requirements for the degree of
Doctor of Philosophy

1939

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1. Lewis S. Combs, M.A. Thesis, Boston University, 1936.
Determination of Wave Lengths of Certain Lines in the
Secondary Spectrum of Hydrogen.

2. H. G. Lacourse and E. B. Hodgdon, Phys. Rev. 52, 96, 1917.
Interferometer Wave Lengths in the Secondary Spectrum
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INTRODUCTION

Much theoretical work is being done on the structure of the hydrogen atom and molecule. The only way to check this theory is to measure the wave lengths of light emitted. The molecular spectrum in particular is very rich in lines in all parts of the visible spectrum as well as in the ultra violet and infra red.

If experimental work is to be used to check theory, the wave length measurements must be made to a high degree of accuracy and practically all the lines in the spectrum must be measured.

Most of these wave length measurements are made by means of a grating in the manner discussed in the writer's M.A. thesis.¹ These measurements can be made with a fair degree of speed but absolute measurements cannot be made accurately with a grating. However, accurate wave lengths may be obtained in terms of the wave lengths of other lines on the plate. This means that the wave lengths of certain lines must be known and used as standards. At the present time it is necessary to photograph the iron spectrum from a Pfund arc on the same plate as the hydrogen spectrum except for a few limited regions where

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W. A. Fowler, M.A. thesis, Boston University, 1938.
Determination of wave lengths of certain lines in the secondary spectrum of hydrogen.

E. A. Lockett and R. E. Johnston, Phys. Rev. 58, 95, 1937.
Interferometer wave lengths in the secondary spectrum of hydrogen.

hydrogen standards have been accurately determined.²

The main drawback to using the iron lines as standards, aside from the extra work involved in arranging the apparatus, is that iron lines often overlap and screen hydrogen lines, which makes accurate measurement of these wave lengths impossible. Also one must take separate plates of the hydrogen and iron spectra and be very careful to distinguish between the iron and hydrogen lines on the plate being measured.

If a few hydrogen lines spaced throughout the spectrum could be measured accurately they could be used as standards and thus speed up the grating measurements considerably. It is the purpose of this paper to discuss a method by which accurate interferometer measurements can be made of certain lines in the hydrogen spectrum to serve as standards.

HISTORICAL

All accurate interferometer measurements of wave length start with Michelson's determination of the standard meter in terms of the wave lengths of the three cadmium lines. His work is generally accepted as the most accurate yet made and his determination of the wave length of the red cadmium line is accepted for the primary standard.

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Pfund arc³ as the source. In 1928 the International Astronomical Union selected certain wave lengths, for which there was good agreement among the several observers, as secondary standards⁴.

The interferometer used in the work described in this paper was developed by Fabry and Perot.⁵ It consists of two plane parallel glass plates, 65% silvered, separated by means of a fused quartz cylinder 10 mm. long, and held in place by three spring clips. The pressure of each spring clip is controlled by an adjusting screw. The two partially silvered surfaces must be very accurately parallel and this condition may be secured by varying the pressure of the spring clips by means of the adjusting screws. This type of interferometer is called an etalon. Etalons were used by all the above mentioned investigators in their measurements of the secondary iron standards.

The first work in making interferometer measurements in the molecular spectrum of hydrogen was done by Gale, Monk, and Lee⁶ in which they made a few scattered measurements throughout the visible spectrum. Their probable errors are rather

3. A.H.Pfund. Astrophys. Jour. 27,296,1908

4. Transactions of International Astronomical Union. III, 86, 1928

5. C. Fabry and Perot. Astrophys. Jour. 15, 73, 1902

6. H.G.Gale, G.S.Monk and K.O.Lee. Astrophys. Jour. 67, 89, 1928

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1. A. W. Stark, *Astronomy*, Jour. 27, 206, 1902
2. *Transactions of International Astronomical Union*, III, 86, 1938
3. G. L. Lewis and Lee, *Astronomy*, Jour. 19, 73, 1902
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large for reasons that will be discussed later and their results are not accurate enough to use as standards in the hydrogen spectrum.

The work of Lacount⁷ and Lacount and Hodgdon² in obtaining interferometer measurements in the hydrogen spectrum was more accurate. Their probable errors being about one fourth the probable errors of Gale, Monk and Lee's⁶ best results. In their work the etalon used was identical with the one used in this investigation as was some of the other apparatus which will be described later.

These few investigators are the only ones to publish results of interferometer measurements in the hydrogen spectrum.

APPARATUS

The apparatus used in this work is located in the Physics Research Room in the basement of the Boston University building at 688 Boylston Street in Boston at the corner of Exeter Street. The vibrations from subway trains under Boylston Street (and now Exeter Street) make necessary a special mounting of the apparatus to "damp out" these vibrations. Also the main steam pipes which pass overhead in the research room require special insulation around the apparatus in the form of a "house" which encloses it completely. The mounting and the insulation are

7. R.G.Lacount Ph.D. Dissertation. Boston University 1935

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V. A. Lacombe Ph. D. Dissertation, Boston University 1933

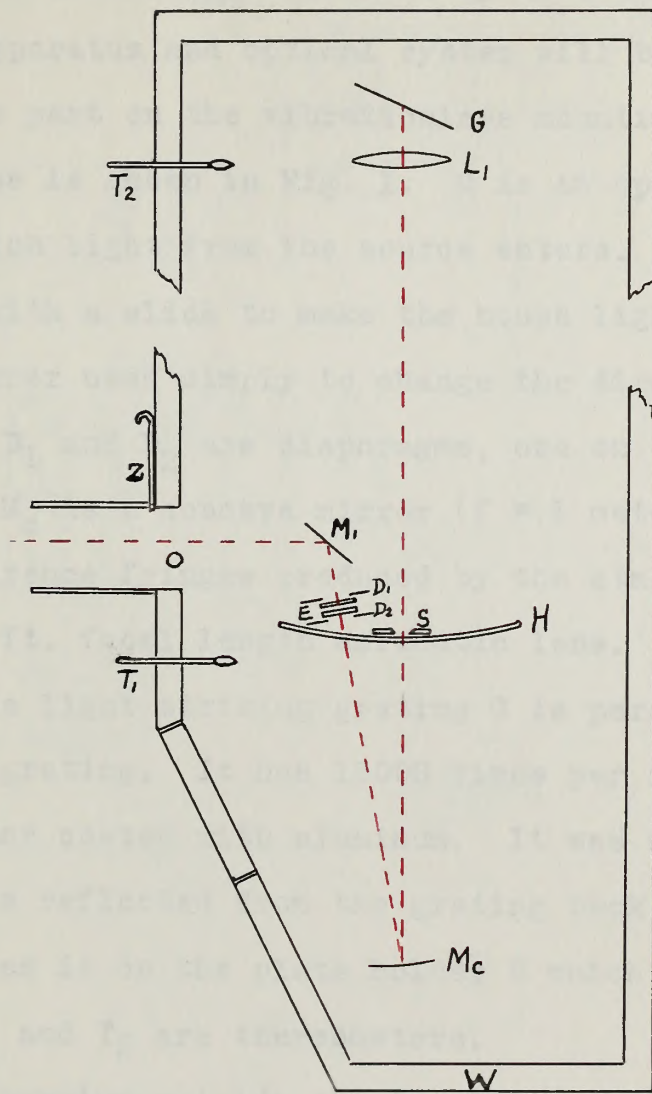
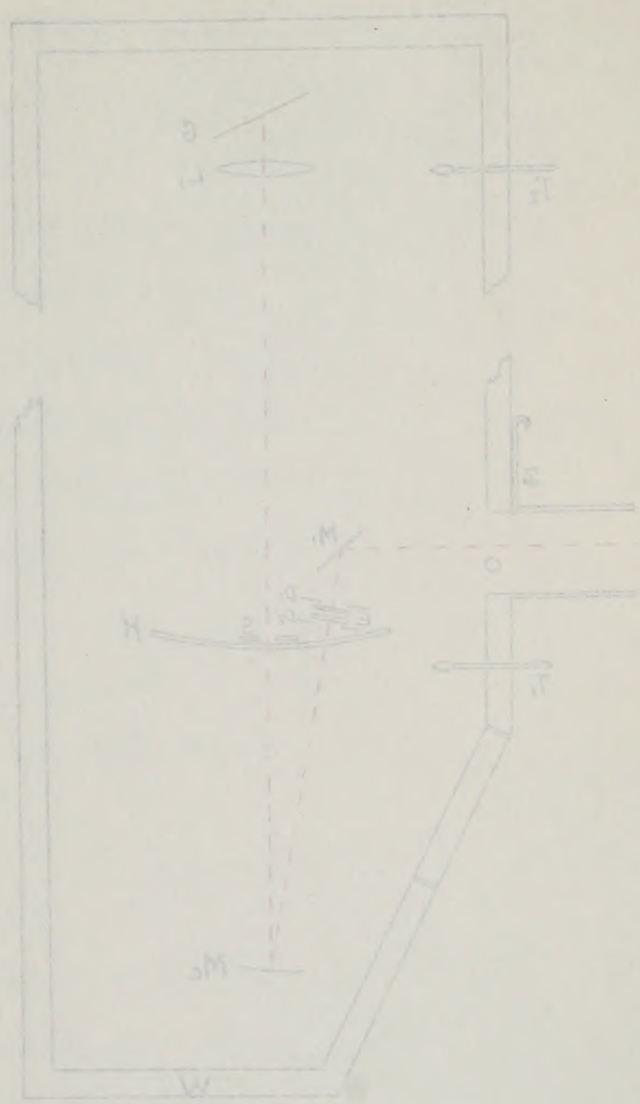


Figure 1
 Not drawn to scale
 Apparatus on Vibrationless Mounting
 in Insulating House

- | | | | |
|-----------|------------------------------|-------|--------------------------------|
| W | Wall of insulating house | E | Etalon |
| O | Opening in wall | M_c | Concave mirror. Front silvered |
| Z | Slide to close opening | S | Adjustable slit |
| $T_{1,2}$ | Thermometers | L_1 | Achromatic lens |
| M_1 | Plane mirror. Front silvered | G | Grating. 15000 lines per inch |
| $D_{1,2}$ | Diaphragms | H | Plate holder |



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| O | Opening in wall |
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| T | Thermometers |
| M | Plane mirror front silvered |
| D | Diaphragm |
| P | Plate holder |
| G | Grating 1500 lines per inch |
| L | Achromatic lens |
| A | Adjustable slit |
| K | Concave mirror front silvered |
| E | Etalon |

described in detail in an article by Kent and Lacount.⁸

The apparatus and optical system will be described in two parts. The part on the vibrationless mounting inside the insulating house is shown in Fig. 1. O is an opening in the house through which light from the source enters. This opening may be closed with a slide to make the house light tight. M_1 is a plane mirror used simply to change the direction of the path of light. D_1 and D_2 are diaphragms, one on each side of the etalon E. M_c is a concave mirror ($f = 1$ meter) which focuses the interference fringes produced by the etalon on the slit S. L_1 is a 30 ft. focal length acromatic lens. S is at the focus of L_1 , hence light striking grating G is parallel. G is a reflection grating. It has 15000 lines per inch on a plane glass surface coated with aluminum. It was ruled by R. W. Wood. The light is reflected from the grating back through lens L_1 which focuses it on the plate holder H which is directly below slit S. T_1 and T_2 are thermometers.

The apparatus outside the insulating house is shown diagrammatically in Fig. 2. With the exception of the transformer V, switches K_1 , K_2 and K_3 and resistance R_1 everything is mounted on one table in the approximate positions shown in the diagram. The transformer is on the floor and the 30000 volt secondary line is well insulated on an overhead framework and drops directly down to the terminals of the tube S_1 . The resis-

8. Norton A. Kent and Reginald G. Lacount. Jour. Optical Soc of America 28,7,1938

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be closed with a slide to make the house light tight. M_1 is a plane mirror used simply to change the direction of the path of light. D_1 and D_2 are diaphragms, one on each side of the station K_0 . K_0 is a concave mirror ($f = 1$ meter) which focuses the interference fringes produced by the station on the slit S_1 .

L_1 is a 30 ft. focal length achromatic lens. S is at the focus of L_1 , hence light striking S is parallel. G is a reflection grating. It has 18000 lines per inch on a plane

glass surface coated with aluminum. It was ruled by R. W. Wood.

The light is reflected from the grating back through lens L_1 which focuses it on the plate holder H which is directly below slit S_1 . T_1 and T_2 are thermometers.

The apparatus outside the insulating house is shown dis-

assembled in Fig. 2. With the exception of the transformer V , resistors R_1 , R_2 and R_3 and resistance R_4 everything is mounted on one table in the approximate positions shown in the

figure. The transformer is on the floor and the 5000 volt secondary line is well insulated on an overhead transformer and

drops directly down to the terminals of the tube S_1 . The resist-

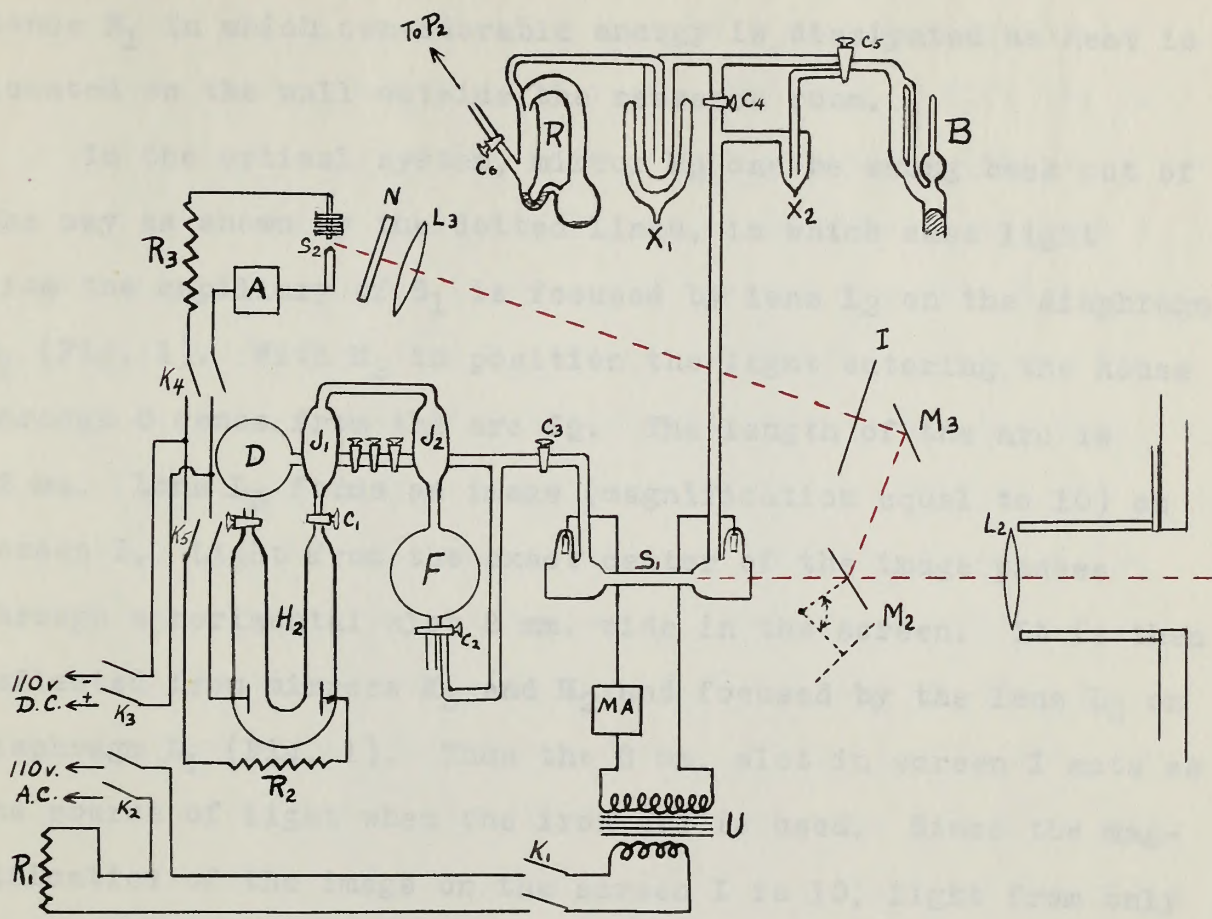


Figure 2
Not drawn to scale

Vacuum System

- H₂ Hydrogen generator
- J_{1,2} Drying tubes
- F Storage flask
- S₁ Discharge tube. Water cooling system not shown.
- X_{1,2} Mercury traps
- B McLeod gauge
- P₁ Diffusion pump
- P₂ Hy-vac oil pump. Not shown.
- C_{1,2,3,4,5,6} Stop cocks
- D Flask of deuterium. Not used in this work.

Electrical System

- S₂ Pfund arc
- U Step-up transformer. 30000 v.
- A Ammeter
- MA Milliammeter
- R_{1,2,3} Resistors
- K_{1,2,3,4,5} Double pole switches

Optical System

- N Glass shield
- L_{2,3} Achromatic lenses
- I Screen with horizontal slot
- M_{2,3} Plane mirrors. Front silvered

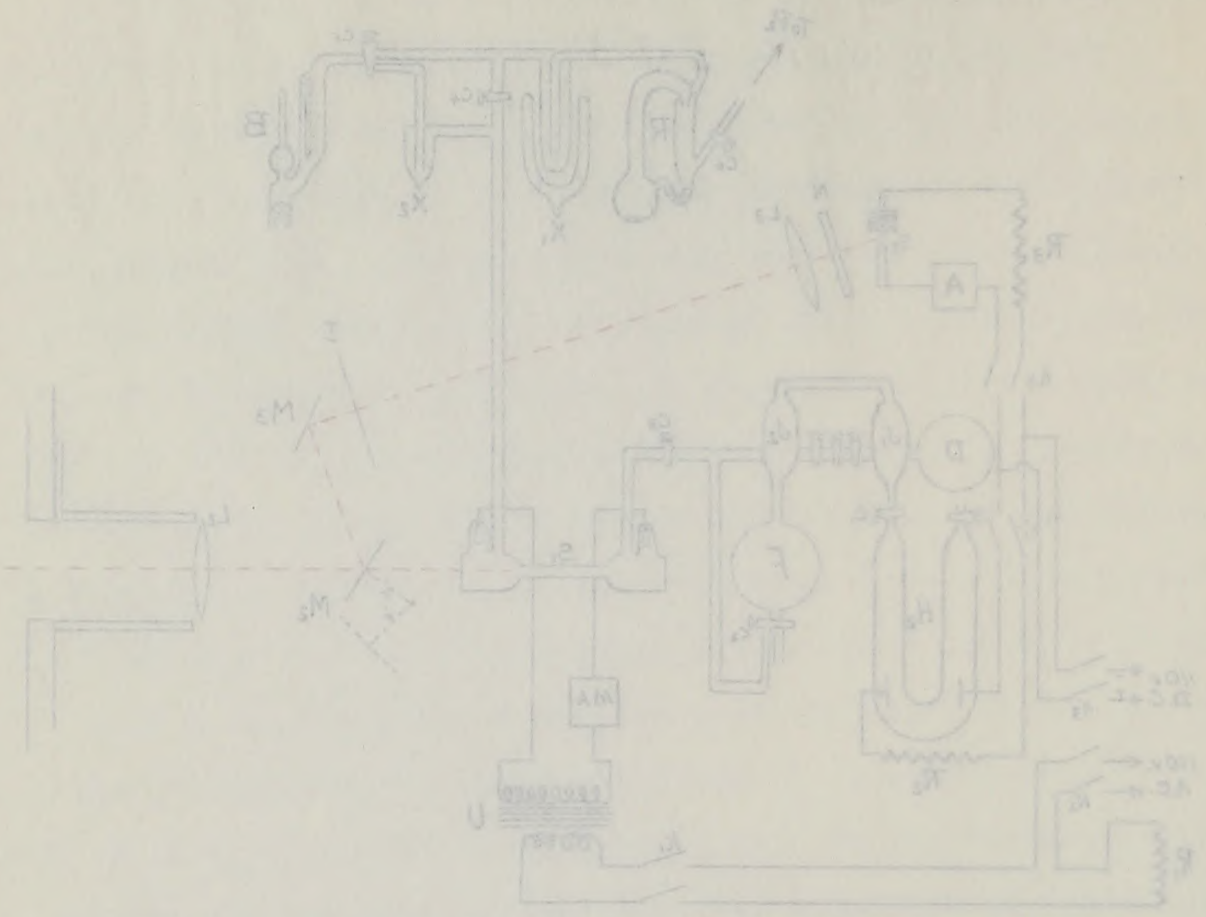


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Vacuum System

- H Hydrogen generator
- J Drying tubes
- F Storage flask
- S Discharge tube Water cooling system not shown
- X Mercury traps
- B McLeod gauge
- P Diffusion pump
- R Hydrocarbon oil pump Not shown
- D Glass of desiccation Not used in this work.

Electrical System

- S1 Fund ac
- U Step-up transformer 3000V
- A Ammeter
- MA Milliammeter
- R1, R2 Resistors
- K1, K2 Double pole switches

Optical System

- M2 Plane mirror Front silvered
- I Screen with horizontal slot
- L Achromatic lenses
- N Glass shield
- M1 Plane mirror

tance R_1 in which considerable energy is dissipated as heat is located on the wall outside the research room.

In the optical system, mirror M_2 can be swung back out of the way as shown by the dotted lines, in which case light from the capillary of S_1 is focused by lens L_2 on the diaphragm D_1 (Fig. 1). With M_2 in position the light entering the house through O comes from the arc S_2 . The length of the arc is 12 mm. Lens L_3 forms an image (magnification equal to 10) on screen I. Light from the exact center of the image passes through a horizontal slot 8 mm. wide in the screen. It is then reflected from mirrors M_3 and M_2 and focused by the lens L_2 on diaphragm D_1 (Fig. 1). Thus the 8 mm. slot in screen I acts as the source of light when the iron arc is used. Since the magnification of the image on the screen I is 10, light from only 0.8 mm. in the center of the arc itself is used.

PROCEDURE

Grating plates of the iron spectrum alone and the hydrogen spectrum alone must be taken in order to identify the lines on the interferometer plates. Therefore the etalon was not used at first. Lens L_2 was adjusted so that an image of the capillary tube S_1 was focused on the slit S or if mirror M_2 was in position an image of the slot in screen I was focused on the slit. In order to make sure that all the optical apparatus was

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properly lined up, a screen with a hole one inch square in the center was placed just in front of lens L_1 , with the hole on the optical axis of the lens. Then a lighted lamp bulb was placed just behind this hole (between the screen and lens L_1). Light from this source then passed through the slit S (opened wide), was reflected from M_c and M_1 and focused by L_2 on the capillary tube. Then if the light passed through the capillary tube of S_1 everything was lined up properly. Then M_2 was swung into position and adjustments made so that the image of the light came exactly at the center of the slot in screen I. Further adjustments of L_3 and arc S_2 were made so that the image formed by L_3 came in the center of the arc itself. These adjustments were very important. If they were not accurately made the intensity of the upper half of the lines on the plate were not the same as of the lower half. The grating was then adjusted for the region between 4800 and 5800 \AA in the first order spectrum. Then the grating was turned and tilted until the spectrum was parallel to and centered in the plate holder H.

The Dewar flask surrounding the mercury trap X_1 had been packed with a slush of solid carbon dioxide and acetone and the pumps had been running for many hours while the adjustments were being made. This was to remove all traces of air and water vapor from the vacuum system. Each night some hydrogen was allowed to enter the system from generator H_2 and in the

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morning the pumps were started again. This was repeated for several days. It is interesting to note here that the pressure always decreased considerably over night due undoubtedly to the absorption of the hydrogen by the platinum electrodes in the discharge tube. This proved that the vacuum system was tight.

The last step in adjusting the apparatus was to get the plate holder into the position of best focus. Using the iron arc as a source, small slant plates were taken in the center of the plate holder and the place where the lines were sharpest noted. Small vertical plates were taken at intervals of 1 mm. on each side of this position and the best focus determined in this way. In the same way the ends and intermediate portion of the plate holder were brought into focus. A grating plate of the iron arc was taken. Next with the hydrogen in the tube at a pressure of approximately 0.3 mm. of mercury a grating plate of the hydrogen spectrum was taken. Finally a plate of both hydrogen and iron was taken.

The etalon was now placed in the system at E (Fig. 1). The incandescent lamp and screen were placed in front of lens L_1 as in lining up the optical system before and the etalon and diaphragms D_1 and D_2 were centered with the image of this light. To make sure that the etalon was normal to the optical axis of the system, it was turned so that the light coming through the slit was reflected from the etalon back onto the

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The etalon was now placed in the system at X (Fig. 1). The incandescent lamp and screen were placed in front of lens I as in lining up the optical system before and the etalon and dispersions D_1 and D_2 were centered with the image of the light. To make sure that the etalon was normal to the optical axis of the system, it was turned so that the light coming through the slit was reflected from the prism back into the

slit again. To make sure that the etalon plates were parallel, the iron arc was replaced with a mercury arc. The rings produced by the interference of light from the green line of mercury were visible on looking into the etalon. If the etalon plates were not parallel, the diameters of the rings changed as the eye was moved from side to side. The adjusting screws were turned until the ring diameters were constant as the eye was moved in any direction. Then the etalon plates were parallel. After rechecking the rest of the apparatus to make sure that all parts were centered on the optical axis, everything was ready for the exposure of an interferometer plate.

The plates used were Eastman Spectroscopic plates type 1-D, emulsion #69338. After the insulating house was made light tight by placing the slide over opening O, a plate was put in the plate holder at night. By morning the temperature inside the house was constant. Then the vacuum system was pumped out and fresh hydrogen let into the system until the pressure was 0.3 mm. of mercury. Since the plates in this particular batch were not very sensitive (although very fine grained) an exposure of 12 hours was necessary. The iron arc was exposed 10 seconds at one hour intervals (130 seconds in all). The pressure was frequently checked and more hydrogen let in if it dropped below 0.3 mm. The current through the tube was 220 m.a. Typical readings for thermometers T_1 and T_2 (for plate 14) were as follows. After putting in the plate, 12 hours before expo-

17

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The plates used were Weston Spectroscopic plates type I-B, emulsion 46933B. After the installation, a plate was put in light by blocking the slide over opening G, a plate was put in the plate holder at right. By turning the temperature inside the house was constant. Then the vacuum system was pumped out and fresh hydrogen fed into the system until the pressure was 0.3 mm of mercury. Since the plates in this particular setup were not very sensitive (although very fine grained) an exposure of 12 hours was necessary. The iron arc was exposed 10 seconds at one hour intervals (100 seconds in all). The pressure was frequently checked and more hydrogen fed in if it dropped below 0.3 mm. The current through the tube was 250 m.a. Typical readings for thermometers T_1 and T_2 (for plate 12) were as follows. After putting in the plate, 12 hours before expo-

sure, $T_1 = 25.9^{\circ}\text{C}$. and $T_2 = 25.7^{\circ}\text{C}$. Here the doors of the house had been open during adjustments. At the beginning of the twelve hour exposure $T_1 = 24.91^{\circ}\text{C}$., $T_2 = 24.70^{\circ}\text{C}$. At the end of the exposure $T_1 = 24.90^{\circ}\text{C}$., $T_2 = 24.68^{\circ}\text{C}$. The largest change during a twelve hour exposure in the summer was 0.4°C . (Plate 13).

The plates were all developed immediately after exposure. The development time was 6 minutes. The developer formula was the Eastman D-19.

By comparing the grating plates of the iron spectrum, the hydrogen spectrum, and the two spectra together, eleven iron lines distributed across the plate were selected to serve as iron standards. Twenty-five hydrogen lines averaging 40 \AA apart were selected to be measured as tertiary standards. These lines were marked on each of the six etalon plates.

The plates were measured with a Gaertner comparator. They were placed in the comparator so that the diameters of the rings to be measured were parallel to the horizontal cross-hair in the telescope. The diameters were measured first with the long wave length end of the plate down (Red lower) and then up (Red upper). Four settings were made on each side of a ring, two with the vertical cross-hair approaching from the left, and two from the right. The method of recording these data is shown below in table 2.

At the beginning of the exposure, $T_1 = 23.9^\circ\text{C}$ and $T_2 = 23.7^\circ\text{C}$. Here the doors of the chamber had been open during adjustments. At the beginning of the twelve hour exposure $T_1 = 24.91^\circ\text{C}$, $T_2 = 24.70^\circ\text{C}$. At the end of the exposure $T_1 = 24.90^\circ\text{C}$, $T_2 = 24.88^\circ\text{C}$. The largest change during a twelve hour exposure in the summer was 0.2°C . (Table 1a).

The plates were all developed immediately after exposure. The development time was 6 minutes. The developer formula was the Weston D-19.

By comparing the grating plates of the iron spectrum, the hydrogen spectrum, and the two spectra together, eleven iron lines identified on the plate were selected to serve as iron standards. Twenty-five hydrogen lines averaging 40 \AA apart were selected to be measured as tertiary standards. These lines were marked on each of the six etalon plates. The plates were measured with a grating comparator. They were placed in the comparator so that the diameters of the rings to be measured were parallel to the horizontal cross-hair in the telescope. The diameters were measured first with the fore eye lens at end of the plate down (Red lower) and then up (Red upper). Four settings were made on each side of a ring, two with the vertical cross-hair extending from the left, and two from the right. The method of recording these data is shown below in Table 2.

CALCULATIONS

The theory of the formation of interference rings by means of an etalon was fully developed by Lacount⁷ in his Ph D. thesis and consequently only a brief summary will be given here.

If t is the distance between the reflecting surfaces of the etalon then the path difference of the interfering rays for normal incidence will be $2t$ and $\frac{2t}{\lambda} =$ the order of interference for wave length λ at normal incidence. This will be the order of interference at the center of the ring system. Call this order of interference p , then

$$p \lambda = 2t \quad (1)$$

Let $P =$ the integral order of interference

Let $\epsilon =$ the fractional order of interference, then

$$p = P + \epsilon \quad (2)$$

For example, if $p = 37740.182$ then $P = 37740.$ and

$$\epsilon = .182$$

$$\text{It can also be shown that } n + \epsilon = K D_n^2 \quad (3)$$

Where $n =$ number of ring (0,1,2,3,etc. starting from the center). Note that the first ring is numbered 0, the second 1, etc.

$D_n =$ the diameter of the n th ring

$K =$ a constant for any one line

If the magnification is constant for the entire plate, it

CALCULATIONS

The theory of the formation of interference rings by means of an etalon was fully developed by Jacquinot in his Ph.D. thesis and consequently only a brief survey will be given here.

If d is the distance between the reflecting surfaces of the etalon then the path difference of the interfering rays for normal incidence will be $2d$ and $\lambda/2$ the order of interference for wave length λ at normal incidence. This will be the order of interference at the center of the ring system. Call this

order of interference p , then
(1) $2d = p\lambda$

Let F = the integral order of interference
Let E = the fractional order of interference, then
(2) $p = F + E$

For example, if $p = 1772.108$ then $F = 1772$, and $E = .108$

(3) It can also be shown that $n + E = \frac{2d}{\lambda}$
where n = number of rings (0, 1, 2, 3, etc.) starting from the center. Note that the first ring is numbered 0, the second 1, etc.

D_n = the diameter of the n th ring
 K = a constant for any one line
If the magnification is constant for the entire plate, if

can be shown that

$$K \lambda = \text{a constant for the whole plate} \quad (4)$$

where K = the above constant for a line of wave length λ .

ϵ may be calculated for any line by means of equation 3 if two or more values of D_n^2 are known. The readings taken on the iron standards are used to calculate $2t$. An approximate value of $2t$ must be known, either from a micrometer measurement or some other source. In this case an approximate value of 18.564 mm. was obtained from Lacount since he had previously used the same etalon for similar measurements. Dividing $2t$ by λ for one iron standard gives a tentative value of P which is probably not in error by more than ± 1 . Then $p = P + \epsilon$ and we can get a corrected value of $2t$ by multiplying λ by this value of p (1). With this new value of $2t$ we calculate tentative values of p for each of the iron lines and compare the decimal part of p with ϵ in each case. We then try increasing the value of P for the first iron line by one, get a new corrected value of $2t$ and get new values of p for each iron line as before. We then decrease P by one and repeat. For one of these sets of values of p the decimal parts should agree well with the values of ϵ . Then the value of P which gave this set of values is correct. If none of the sets of values checks well we must continue to increase or decrease P until good agreement is secured. When this result is achieved the integral part of p is the correct value of P for each iron line. We

can be shown that

$$K_A = \text{constant for the whole glass}$$

where $K =$ the above constant for a line of wave length λ .

λ may be calculated for any line by means of equation 3 if two or more values of θ_0 are known. The readings taken on the iron standards are used to calculate θ_0 . An approximate value of θ_0 must be known, either from a micrometer measurement or some other source. In this case an approximate value of 18.504 mm. was obtained from a recent check he had previously

used the same setup for similar measurements. Dividing θ_0 by 4 for one standard gives a tentative value of λ which is probably not in error by more than ± 1 . Then $\theta = \theta_0 + \epsilon$ and we can get a corrected value of θ_0 by multiplying λ by this

value of θ . With this new value of θ_0 we calculate tentative values of λ for each of the iron lines and compare the decimal part of λ with ϵ in each case. We then try increasing

the value of θ_0 for the first iron line by one, get a new corrected value of λ and get new values of λ for each iron line as before. We then decrease θ_0 by one and repeat. For one

of these sets of values of λ the decimal parts should agree well with the value of ϵ . Then the value of θ_0 which gave this set of values is correct. If none of the sets of values checks

well we must continue to increase or decrease θ_0 until good agreement is secured. When this result is achieved the integral part of λ is the correct value of λ for each iron line. We

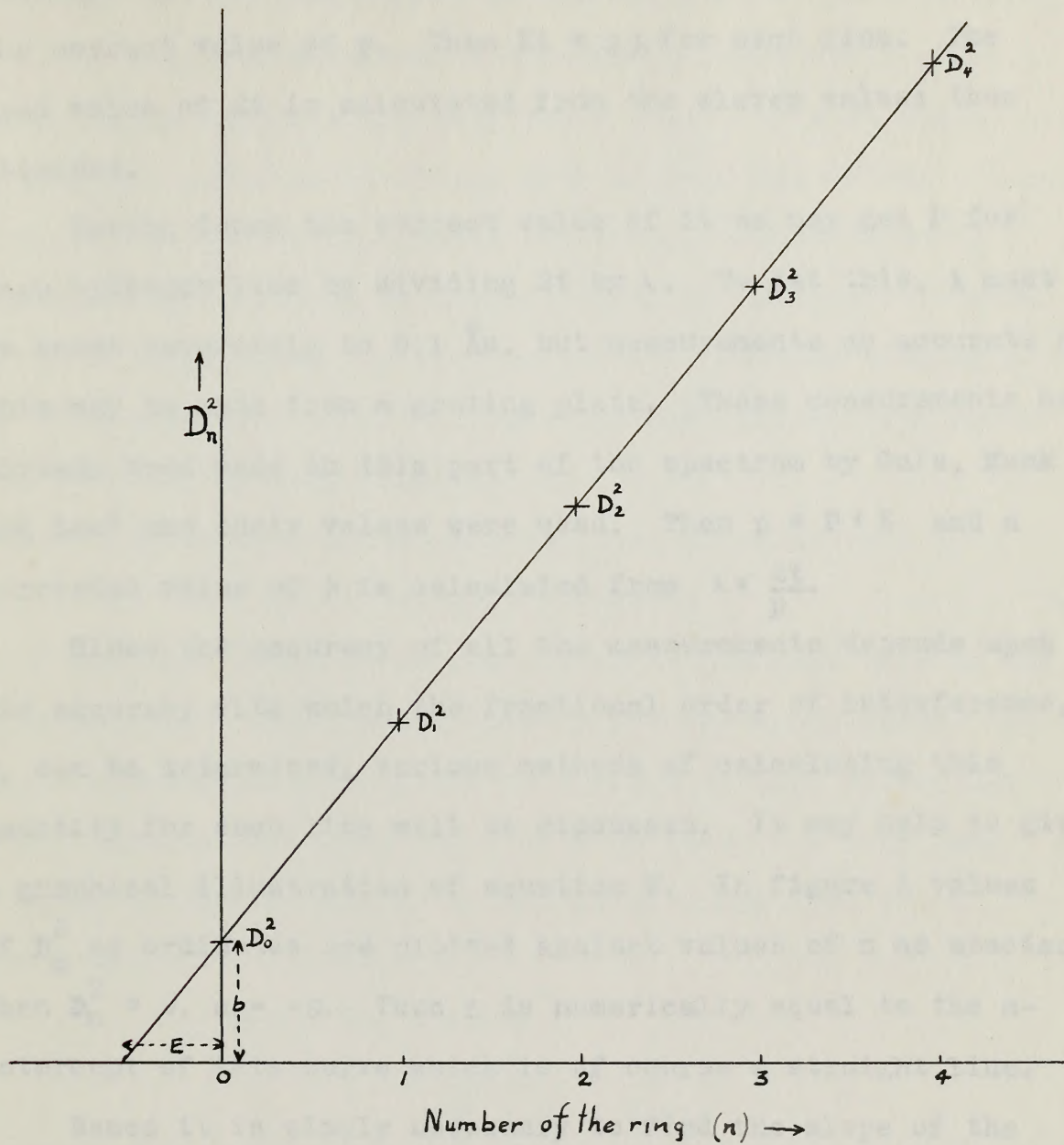
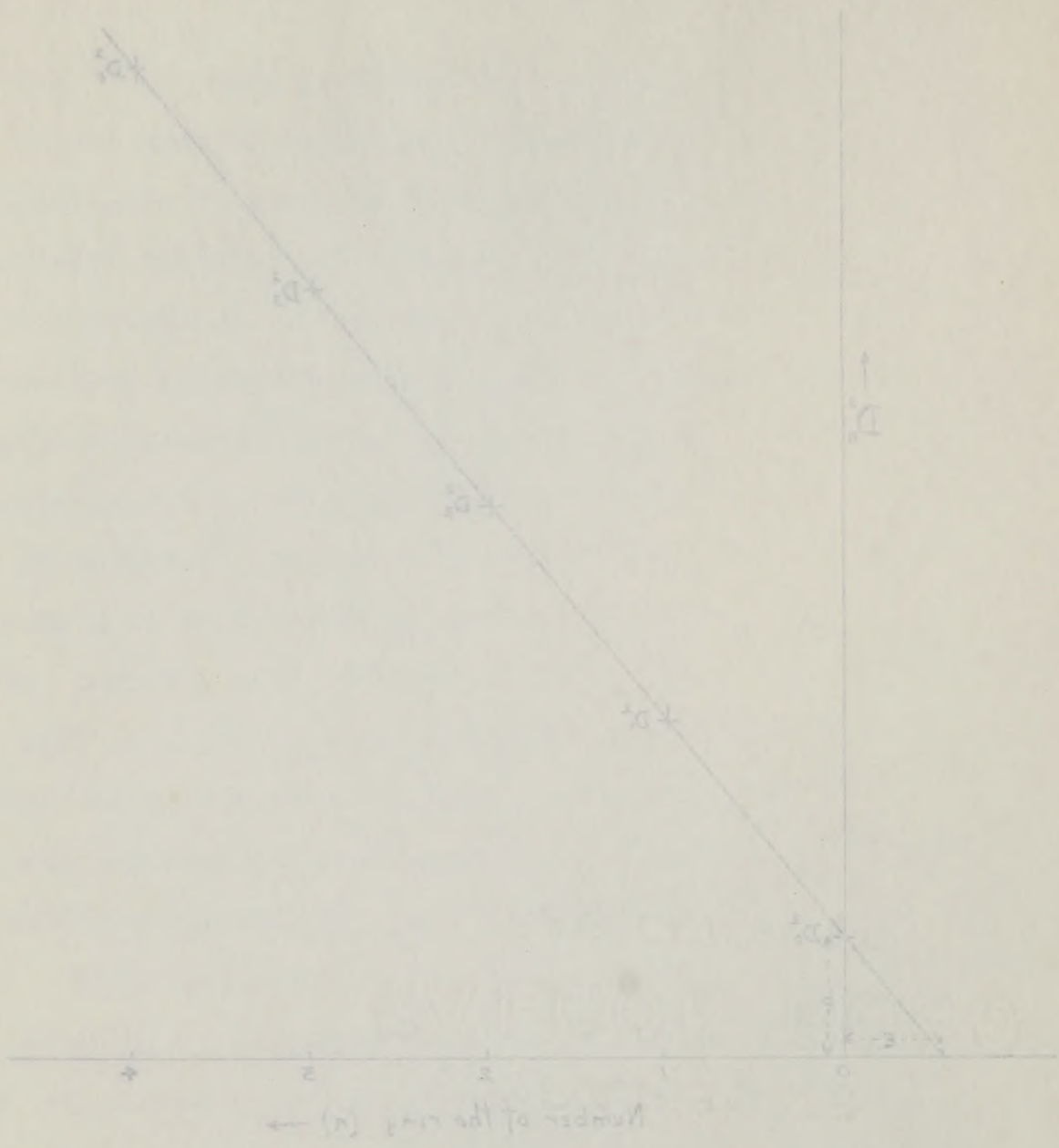


Figure 3

Graph of $KD_n^2 = n + E - D_n^2$ plotted against n



Graph of $KD_n^2 = n + E - D_n$ plotted against n
 Figure 3

then add to this the calculated value of ϵ in each case to get the correct value of p . Then $2t = p\lambda$ for each line. The mean value of $2t$ is calculated from the eleven values thus obtained.

Having found the correct value of $2t$ we may get P for each hydrogen line by dividing $2t$ by λ . To get this, λ must be known accurately to 0.1 \AA . but measurements as accurate as this may be made from a grating plate. These measurements had already been made in this part of the spectrum by Gale, Monk and Lee⁶ and their values were used. Then $p = P + \epsilon$ and a corrected value of λ is calculated from $\lambda = \frac{2t}{p}$.

Since the accuracy of all the measurements depends upon the accuracy with which the fractional order of interference, ϵ , can be determined, various methods of calculating this quantity for each line will be discussed. It may help to give a graphical illustration of equation 3. In figure 3 values of D_n^2 as ordinates are plotted against values of n as abscissas. When $D_n^2 = 0$, $n = -\epsilon$. Thus ϵ is numerically equal to the n -intercept of this curve which is of course a straight line.

Hence it is simply necessary to find the slope of the curve and divide it into D_0^2 to obtain ϵ . This was the method used by Gale, Monk and Lee in obtaining their interferometer wave lengths⁶. This method, however, does not give consistently accurate values of ϵ . From figure 3 we see that ϵ is obtained by extrapolation. A slight error in the slope of the

then add to this the calculated value of ϵ in each case to get the correct value of λ . Then $\lambda = \lambda_0 / \epsilon$ for each line. The mean value of λ is calculated from the eleven values thus obtained.

Having found the correct value of λ we may get ϵ for each hydrogen line by dividing λ by λ_0 . To get this, λ must be known accurately to 0.1 Å. but measurements as accurate as this may be made from a grating plate. These measurements had already been made in this part of the spectra by Gale, Monk and Lee⁶ and their values were used. Then $\epsilon = \lambda / \lambda_0$ and a

$$\text{corrected value of } \lambda \text{ is calculated from } \lambda = \frac{\lambda_0}{\epsilon}$$

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Hence it is simply necessary to find the slope of the curve and divide it into D_0^2 to obtain ϵ . This was the method used by Gale, Monk and Lee in obtaining their interferometer wave lengths⁶. This method, however, does not give consistently accurate values of ϵ . From figure 3 we see that ϵ is obtained by extrapolation. A slight error in the slope of the

line may cause a large error in the value of ϵ since swinging the line slightly will make a relatively large difference in the point of intersection with the n axis. This is shown very clearly if one tries to obtain ϵ by a graphical method. Values of D_n^2 may be plotted against n as in figure 3 and then a straight line obtained by holding a tightly stretched thread so that it best fits the plotted points. Careful placing of the thread several times will give as many values of ϵ which will be found to vary considerably.

The above method does not make use of equation 4,

$$K \lambda = \text{the plate constant}$$

If we use that equation we can obtain $K \lambda$ for each line on the plate and get a mean plate constant for the whole plate. If then this mean plate constant be divided by each individual wave length, a corrected value of K is found for each line. K is equal to the reciprocal of the slope since from the

$$\text{equations } K D_0^2 = \epsilon$$

$$\text{and } K D_1^2 = 1 + \epsilon$$

$$K = \frac{1}{D_1^2 - D_0^2} = \frac{1}{\text{slope}}$$

Thus from the corrected value of K a corrected value of the slope of each line may be found which is obtained by using all measurements on the plate, rather than those of one line alone.

In practice it was found that using the eleven iron standards to obtain the mean plate constant gave as good results as using

line may cause a large error in the value of ϵ since extending the line slightly will make a relatively large difference in the point of intersection with the x-axis. This is shown very clearly if one tries to obtain ϵ by a graphical method. Values of D_0^2 may be plotted against μ as in figure 3 and then a straight line obtained by holding a tightly stretched thread so that it best fits the plotted points. Careful placing of the thread several times will give as many values of ϵ which will be found to vary considerably.

The above method does not make use of equation 4,

$$K_A = \text{the plate constant}$$

If we use that equation we can obtain K_A for each line on the plate and get a mean plate constant for the whole plate. If then this mean plate constant be divided by each individual wave length, a corrected value of K is found for each line. K is equal to the reciprocal of the slope since from the

$$\begin{aligned} \text{equations} \quad K D_0^2 &= \epsilon \\ \text{and} \quad K D_1^2 &= 1 + \epsilon \\ K &= \frac{1}{D_1^2 - D_0^2} = \frac{1}{\text{slope}} \end{aligned}$$

Thus from the corrected value of K a corrected value of the slope of each line may be found which is obtained by using all measurements on the plate, rather than those of one line alone. In practice it was found that using the eleven iron standards to obtain the mean plate constant gave as good results as using

all the lines measured. This method was used by Lacount⁷ in his interferometer measurements, and thus his results have a smaller probable error than those of Gale, Monk and Lee⁶. However, in obtaining the slope of the curve for each line Lacount used only two ring diameters. This is theoretically sound since a straight line may be determined by two points. But if more points are plotted, certainly greater accuracy should be obtained, particularly in the final step in obtaining ϵ in which D_n^2 is divided by the corrected slope. Then too it seems reasonable to use all the data available on the plate. The writer first tried the method used by Lacount of measuring the diameters of two rings only and obtaining the mean slope from that. After measuring three plates (12, 13 and 14) and calculating the wave lengths of the hydrogen lines, spreads as high as .007 Å. were found. This was too high since good accuracy to three decimal places was desired.

On the last three plates (16, 17 and 18) the diameters of four rings were measured on each line. On one plate (18) the calculations were made by the method used by Gale, Monk and Lee⁶. Curves like that in figure 3 were plotted for each line on large cross-section paper (50 x 100 cm.) and ϵ found for each line by stretching a thread so that it best fitted the points and reading off ϵ . On the whole the wave lengths checked fairly well with the averages of those already found. A few were considerably off, and the writer found that by restretching

all the lines measured. This method was used by Lacombe in his interferometer measurements, and thus his results have a smaller probable error than those of Gale, Monk and Lee. However, in obtaining the slope of the curve for each line Lacombe used only two ring diameters. This is theoretically sound since a straight line may be determined by two points. But if more points are plotted, certainly greater accuracy should be obtained, particularly in the final step in obtaining λ in which D_n^2 is divided by the corrected slope. Then too it seems reasonable to use all the data available on the plate. The writer first tried the method used by Lacombe of measuring the diameters of two rings only and obtaining the mean slope from that. After measuring three plates (I, II and III) and adjusting the wave lengths of the hydrogen lines, spectra as high as 0.07 μ were found. This was too high since good accuracy to three decimal places was desired. On the last three plates (IV, V and VI) the diameters of four rings were measured on each line. On one plate (IV) the calculations were made by the method used by Gale, Monk and Lee. Curves like that in figure 2 were plotted for each line on large cross-section paper (20 x 100 cm.) and λ found for each line by stretching a thread so that it best fitted the points and reading off λ . On the whole the wave lengths checked fairly well with the averages of those already found. A few were considerably off, and the writer found that by replotting

the thread through the plotted points he could invariably obtain a new value of ϵ that would give better results! This method was discarded as not being accurate enough. Besides, it proved to be physically tiring to plot the points and stretch the thread on such large cross-section paper.

For plates 16 and 17 three values of the slope were obtained for each iron line:

$$\frac{D_3^2 - D_0^2}{3}, \quad \frac{D_3^2 - D_1^2}{2} \text{ and } \frac{D_2^2 - D_0^2}{2}$$

These were averaged, a plate constant obtained for each line, and a mean plate constant obtained from the eleven iron lines. The hydrogen wave lengths calculated by this method for these plates checked very well, but were lower than the averages obtained from the first three plates. Then for plates 16 and 17 a mean plate constant was obtained by using all 36 lines (11 iron and 25 hydrogen). This plate constant was higher for each plate than the one obtained from the iron lines alone. This gave a larger value for $2t$ for each plate but, surprisingly enough, the calculated values of the hydrogen wave lengths came out practically the same. This is explained as follows:

$$\lambda = \frac{2t}{p} \quad \text{and} \quad 2t = p_s \lambda_s$$

where p_s is the order of interference of standard wave length λ_s

$$\text{Therefore} \quad \lambda = \frac{p_s \lambda_s}{p}$$

the thread through the gilded points in each invariably
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For plates 16 and 17 three values of the slope were
 obtained for each line:

$$\frac{D_2^2 - D_1^2}{\lambda^2} \quad \text{and} \quad \frac{D_3^2 - D_1^2}{\lambda^2} \quad \text{and} \quad \frac{D_3^2 - D_2^2}{\lambda^2}$$

These were averaged, a plate constant obtained for each line,
 and a mean plate constant obtained from the eleven iron lines.
 The hydrogen wave lengths calculated by this method for these
 plates checked very well, but were lower than the averages ob-
 tained from the first three plates. Then for plates 18 and 19
 a mean plate constant was obtained by using all 35 lines (11
 iron and 24 hydrogen). This plate constant was higher for each
 plate than the one obtained from the iron lines alone. This
 gave a larger value for λ for each plate but, surprisingly
 enough, the calculated values of the hydrogen wave lengths
 came out practically the same. This is explained as follows:

$$\lambda = \frac{2t}{p} \quad \text{and} \quad \lambda = \frac{2t}{p} \lambda_0$$

where λ_0 is the order of interference of standard wave length λ_0

$$\lambda = \frac{2t}{p} \lambda_0$$

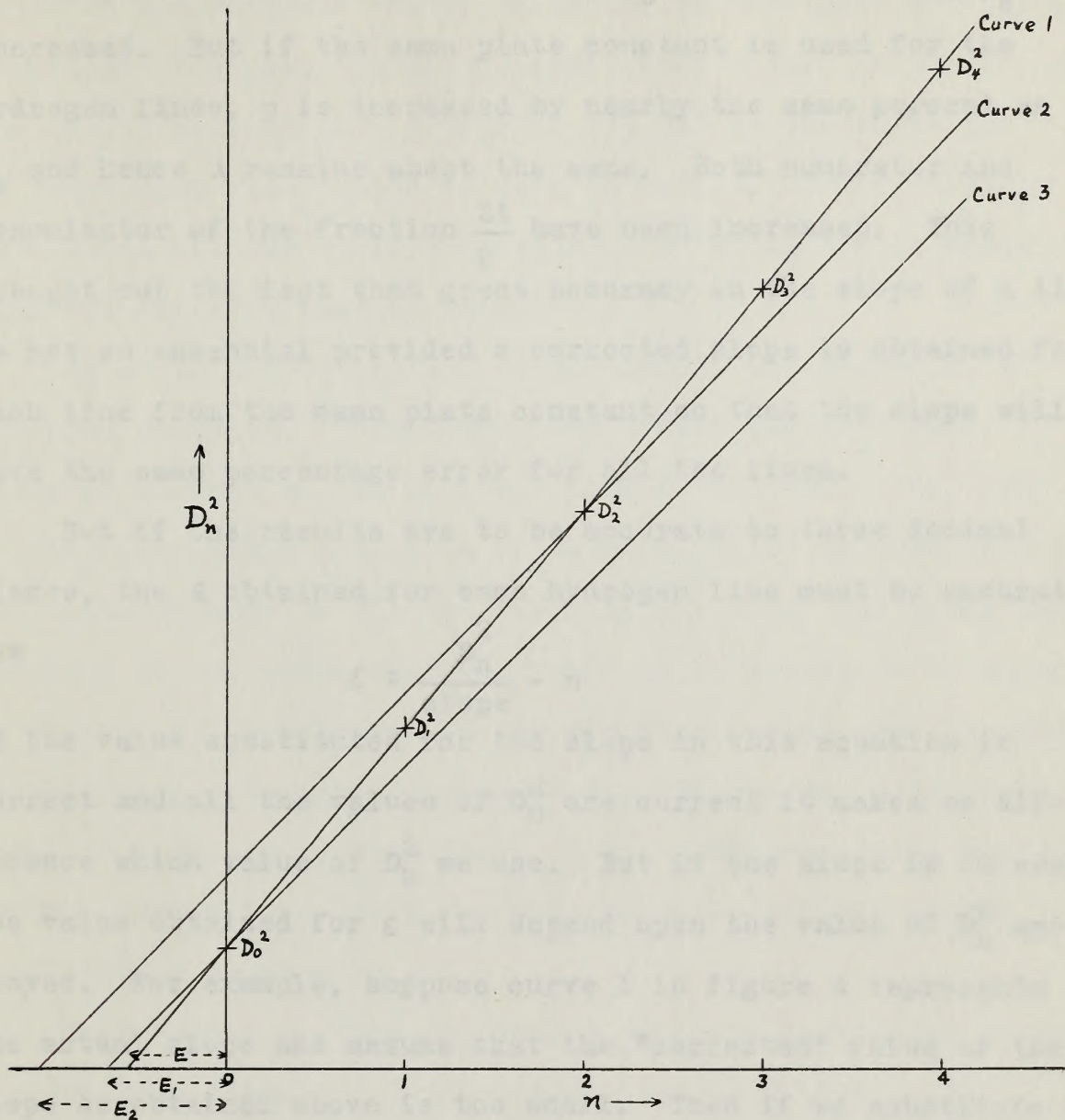


Figure 4

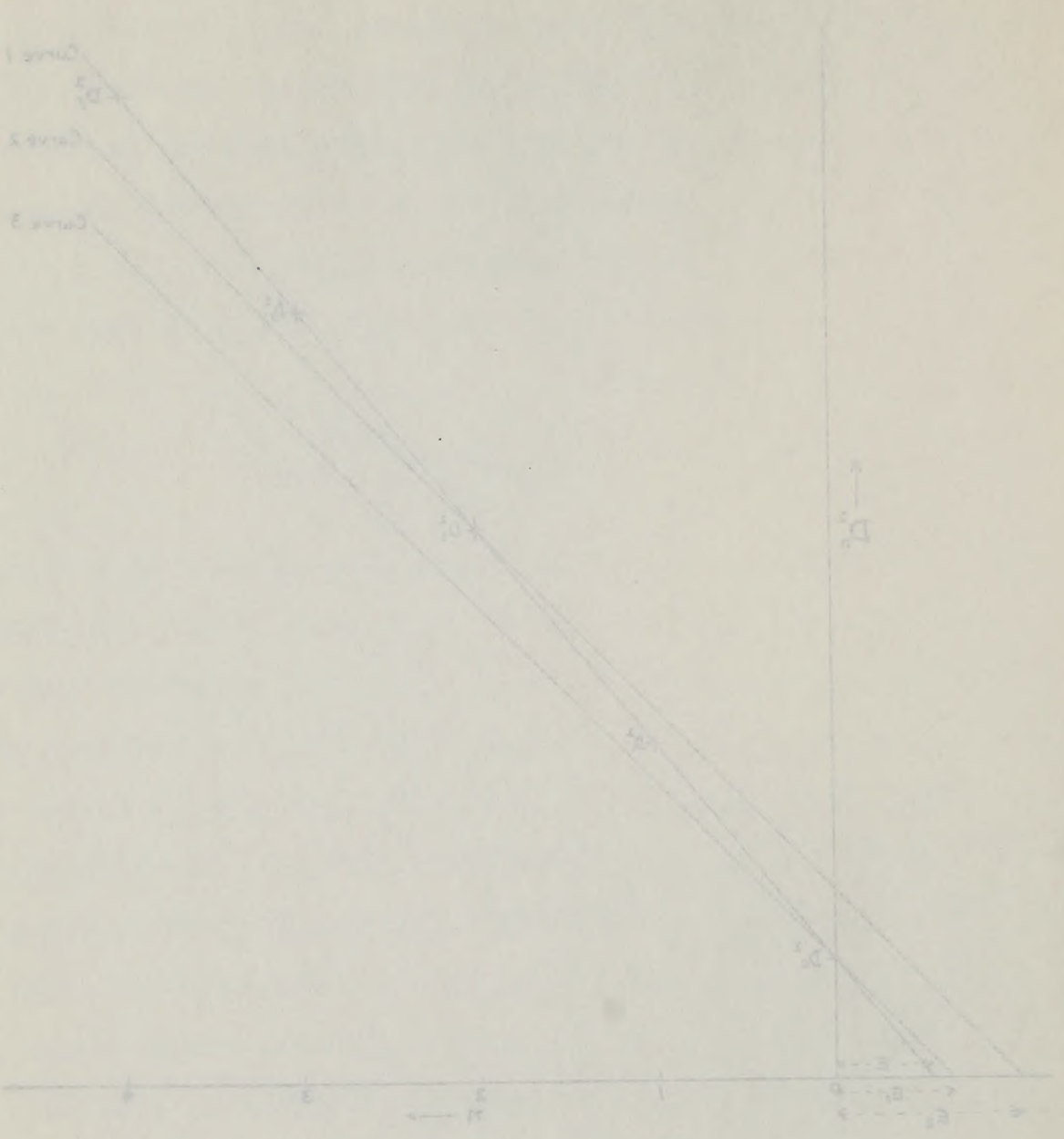


Figure 4

If the plate constant is increased, ϵ_s is increased and p_s is increased. But if the same plate constant is used for the hydrogen lines, p is increased by nearly the same percent as p_s and hence λ remains about the same. Both numerator and denominator of the fraction $\frac{2t}{p}$ have been increased. This brought out the fact that great accuracy in the slope of a line is not so essential provided a corrected slope is obtained for each line from the mean plate constant so that the slope will have the same percentage error for all the lines.

But if the results are to be accurate to three decimal places, the ϵ obtained for each hydrogen line must be accurate.

Now

$$\epsilon = \frac{D_n^2}{\text{slope}} - n$$

If the value substituted for the slope in this equation is correct and all the values of D_n^2 are correct it makes no difference which value of D_n^2 we use. But if the slope is in error the value obtained for ϵ will depend upon the value of D_n^2 employed. For example, suppose curve 1 in figure 4 represents the actual slope and assume that the "corrected" value of the slope as obtained above is too small. Then if we substitute D_0^2 in the above equation we should get the value ϵ_1 for ϵ . If we substitute D_2^2 we should get ϵ_2 . Curves 2 and 3 are drawn having the "corrected" slope. It would seem then that D_0^2 should be used in every case since a line drawn through it with a slope slightly in error will give a value for ϵ more nearly

If the plate constant is increased, ϵ_0 is increased and μ_0 is increased. But if the same plate constant is used for the hydrogen lines, μ_0 is increased by nearly the same percent as μ_0 and hence λ remains about the same. Both numerator and denominator of the fraction $\frac{\lambda}{\epsilon_0}$ have been increased. This brought out the fact that great accuracy in the slope of a line is not so essential provided a corrected slope is obtained for each line from the mean plate constant so that the slope will have the same percentage error for all the lines.

But if the results are to be accurate to three decimal places, the ϵ_0 obtained for each hydrogen line must be accurate.

$$\epsilon = \frac{D_n^S}{\text{slope}}$$

If the value substituted for the slope in this equation is correct and all the values of D_n^S are correct it makes no difference which value of D_n^S we use. But if the slope is in error the value obtained for ϵ will depend upon the value of D_n^S employed. For example, suppose curve 1 in figure 4 represents the actual slope and assume that the "corrected" value of the slope as obtained above is too small. Then if we substitute D_n^S in the above equation we should get the value ϵ_1 for ϵ . If we substitute D_n^S we should get ϵ_2 . Curves 2 and 3 are drawn having the "corrected" slope. It would seem then that D_n^S should be used in every case since a line drawn through it with a slope slightly in error will give a value for ϵ more nearly

equal to the accurate value. However, we have seen that errors in ϵ tend to cancel out if the same error occurs in the ϵ 's of the iron lines (which are used to get $2t$) as occurs in the ϵ of a hydrogen line (which is used to get p). Hence it would be best to use the corrected value of D_n^2 which can be calculated with the greatest accuracy.

It would not be logical to use simply the square of a measured diameter. This would have a high probable error since it depends on the settings made on only one ring. We should calculate a corrected value of D_n^2 which depends on all the settings made on all the rings of one line. Although the accuracy of the slope does not now seem so important it would be convenient to calculate it by the same method that is used in obtaining a corrected value of D_n^2 . Of course, both these could be obtained by plotting a curve on cross-section paper but the writer feels that for himself at least this method would not be dependable.

There comes to mind the method of least squares as probably the best method of finding the slope of a line drawn through 4 or 5 experimentally located points, and also of finding corrected values of the points.

Referring to figure 3

$$\text{Let } y_n = D_n^2$$

a = slope of line

b = y intercept

equal to the accurate value. However, we have seen that errors in ϵ tend to cancel out if the same error occurs in the ϵ 's of the iron lines (which are used to get S_1) as occurs in the ϵ 's of a hydrogen line (which is used to get p). Hence it would be best to use the corrected value of D_n^2 which can be calculated with the greatest accuracy.

It would not be logical to use simply the square of a measured diameter. This would have a high probable error since it depends on the readings made on only one ring. We should calculate a corrected value of D_n^2 which depends on all the readings made on all the rings of one line. Although the accuracy of the slope does not seem as important it would be convenient to calculate it by the same method that is used in obtaining a corrected value of D_n^2 . Of course, both these could be obtained by plotting a curve on cross-section paper but the writer feels that for himself at least this method would not be desirable.

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Referring to figure 3

$$\text{Let } Y_n = D_n^2$$

$$a = \text{slope of line}$$

$$b = y \text{ intercept}$$

$$\text{Then } y_n = an + b \quad (1)$$

Using the least squares method

$$(y_n - an - b)^2 = v_n^2 \quad (2)$$

$$v_0^2 + v_1^2 + v_2^2 + \dots = \sum (v_n^2) = M$$

$$\frac{\partial M}{\partial a} = 0 = \sum_n 2(y_n - an - b)(-n)$$

$$(-0y_0 - 1y_1 - 2y_2 \dots ny_n) + (0a + 1^2a + 2^2a + \dots n^2a) + (0b + 1b + \dots nb) = 0$$

$$\frac{\partial M}{\partial b} = 0 = \sum_n 2(y_n - an - b)(-1)$$

$$(-y_0 - y_1 - y_2 \dots y_n) + (0a + 1a + 2a + \dots na) + (n + 1)b = 0$$

$$\text{Let } A = D_1^2 + 2D_2^2 + 3D_3^2 + \dots nD_n^2$$

$$B = 1^2 + 2^2 + \dots n^2$$

$$C = 1 + 2 + \dots n$$

$$F = D_0^2 + D_1^2 + \dots D_n^2$$

$$n = \text{number of ring } (0, 1, 2, \dots, n)$$

$$N = \text{total number of rings} = n + 1$$

$$\text{Then } Ba + Cb = A$$

$$Ca + Nb = F$$

$$\text{and } a = \frac{AN - CF}{BN - C^2} \quad (5)$$

$$b = \frac{BF - AC}{BN - C^2} \quad (6)$$

Then $M_n = an + b$

Using the least squares method

$$S_n = \sum_{i=1}^n (y_i - an - b)^2$$

$$M = \sum_{i=1}^n (y_i - an - b)^2 = \dots + y_1^2 + y_2^2 + \dots + y_n^2$$

$$\frac{dM}{da} = 0 = \sum_{i=1}^n 2(y_i - an - b)(-n) = 0$$

$$(-2n)(y_1 - ay_1 - by_1 - ay_2 - by_2 - \dots - ay_n - by_n) + (2n^2a + 2nby_1 + 2nby_2 + \dots + 2nby_n) = 0$$

$$\frac{dM}{db} = 0 = \sum_{i=1}^n 2(y_i - an - b)(-1) = 0$$

$$(-2)(y_1 - ay_1 - by_1 - ay_2 - by_2 - \dots - ay_n - by_n) + (2ay_1 + 2ay_2 + \dots + 2ay_n) = 0$$

$$\text{Let } A = \sum_{i=1}^n y_i^2 + 2ay_1y_2 + \dots + 2ay_{n-1}y_n$$

$$B = y_1^2 + y_2^2 + \dots + y_n^2$$

$$C = y_1 + y_2 + \dots + y_n$$

$$D = y_1^2 + y_2^2 + \dots + y_n^2$$

n = number of rings (0, 1, 2, ..., n)

M = total number of rings = $n + 1$

$$\text{Then } Ba + Cb = A$$

$$Ca + Mb = B$$

(a) $a = \frac{AM - CB}{BM - C^2}$ and $b = \dots$

(b) $b = \frac{BM - AC}{BM - C^2}$

$$D_n^2 = b + na \quad (7)$$

$$\frac{D_n^2}{a} = n + \epsilon \quad (8)$$

A value of the slope (a) may be calculated for each iron line by means of equation 5. The plate constant for each line ($\frac{\lambda}{a}$) may be calculated and the mean plate constant obtained. From this a corrected value of the slope for each line may be obtained.

Next comes the problem as to which corrected value of D_n^2 can be calculated with the smallest probable error. To solve this problem let us use the "cut and try" method.

Let the correct values of D_n^2 for five rings equal 1, 3, 5, 7, 9

Let the correct slope = 2

Now suppose that D_0^2 is in error by +.01 and calculate by the least squares method corrected values of D_n^2

D_n^2	nD_n^2	$C = 0+1+2+3+4 = 10$	
$D_0^2 = 1.01$	0	$B = 0+1^2+2^2+3^2+4^2 = 30$	
$D_1^2 = 3$	3	$BF = 750.3$	$AN = 350$
$D_2^2 = 5$	10	$AC = \underline{700}$	$CF = \underline{250.1}$
$D_3^2 = 7$	21	50.3	99.9
$D_4^2 = \underline{9}$	<u>36</u>	$BN - C^2 = 50$	
$F = 25.01$	$A = 70$		

(7) $D_n^2 = a + na$

(8) $\frac{D_n^2}{n} = n + a$

A value of the slope (a) may be calculated for each line by means of equation 8. The plate constant for each line ($\frac{1}{\lambda}$) may be calculated and the mean plate constant obtained.

From this a corrected value of the slope for each line may be obtained. Next comes the problem as to which corrected value of D_n^2 can be calculated with the smallest probable error. To solve this problem let us use the "cut and try" method.

Let the correct values of D_n^2 for five rings equal 1, 3, 5, 7, 9

Let the correct slope = 2
 Now suppose that D_n^2 is in error by +.01 and calculate by the least squares method corrected values of D_n^2

D_n^2	D_n^2	D_n^2	D_n^2	D_n^2
1.01	1	1	1	1
3.01	3	3	3	3
5.01	5	5	5	5
7.01	7	7	7	7
9.01	9	9	9	9
$\Sigma = 26.05$	$\Sigma = 26$	$\Sigma = 26$	$\Sigma = 26$	$\Sigma = 26$
$\Sigma D_n^2 = 130.25$	$\Sigma D_n^2 = 130$	$\Sigma D_n^2 = 130$	$\Sigma D_n^2 = 130$	$\Sigma D_n^2 = 130$
$\Sigma D_n^4 = 100.51$	$\Sigma D_n^4 = 100$	$\Sigma D_n^4 = 100$	$\Sigma D_n^4 = 100$	$\Sigma D_n^4 = 100$
$\Sigma D_n^6 = 420.7$	$\Sigma D_n^6 = 420$	$\Sigma D_n^6 = 420$	$\Sigma D_n^6 = 420$	$\Sigma D_n^6 = 420$
$\Sigma D_n^8 = 160.41$	$\Sigma D_n^8 = 160$	$\Sigma D_n^8 = 160$	$\Sigma D_n^8 = 160$	$\Sigma D_n^8 = 160$
$\Sigma D_n^{10} = 63.05$	$\Sigma D_n^{10} = 63$	$\Sigma D_n^{10} = 63$	$\Sigma D_n^{10} = 63$	$\Sigma D_n^{10} = 63$
$\Sigma D_n^{12} = 24.3$	$\Sigma D_n^{12} = 24$	$\Sigma D_n^{12} = 24$	$\Sigma D_n^{12} = 24$	$\Sigma D_n^{12} = 24$
$\Sigma D_n^{14} = 9.2$	$\Sigma D_n^{14} = 9$	$\Sigma D_n^{14} = 9$	$\Sigma D_n^{14} = 9$	$\Sigma D_n^{14} = 9$
$\Sigma D_n^{16} = 3.3$	$\Sigma D_n^{16} = 3$	$\Sigma D_n^{16} = 3$	$\Sigma D_n^{16} = 3$	$\Sigma D_n^{16} = 3$
$\Sigma D_n^{18} = 1.2$	$\Sigma D_n^{18} = 1$	$\Sigma D_n^{18} = 1$	$\Sigma D_n^{18} = 1$	$\Sigma D_n^{18} = 1$
$\Sigma D_n^{20} = 0.4$	$\Sigma D_n^{20} = 0$	$\Sigma D_n^{20} = 0$	$\Sigma D_n^{20} = 0$	$\Sigma D_n^{20} = 0$
$\Sigma D_n^{22} = 0.1$	$\Sigma D_n^{22} = 0$	$\Sigma D_n^{22} = 0$	$\Sigma D_n^{22} = 0$	$\Sigma D_n^{22} = 0$
$\Sigma D_n^{24} = 0.05$	$\Sigma D_n^{24} = 0$	$\Sigma D_n^{24} = 0$	$\Sigma D_n^{24} = 0$	$\Sigma D_n^{24} = 0$
$\Sigma D_n^{26} = 0.02$	$\Sigma D_n^{26} = 0$	$\Sigma D_n^{26} = 0$	$\Sigma D_n^{26} = 0$	$\Sigma D_n^{26} = 0$
$\Sigma D_n^{28} = 0.01$	$\Sigma D_n^{28} = 0$	$\Sigma D_n^{28} = 0$	$\Sigma D_n^{28} = 0$	$\Sigma D_n^{28} = 0$
$\Sigma D_n^{30} = 0.005$	$\Sigma D_n^{30} = 0$	$\Sigma D_n^{30} = 0$	$\Sigma D_n^{30} = 0$	$\Sigma D_n^{30} = 0$
$\Sigma D_n^{32} = 0.002$	$\Sigma D_n^{32} = 0$	$\Sigma D_n^{32} = 0$	$\Sigma D_n^{32} = 0$	$\Sigma D_n^{32} = 0$
$\Sigma D_n^{34} = 0.001$	$\Sigma D_n^{34} = 0$	$\Sigma D_n^{34} = 0$	$\Sigma D_n^{34} = 0$	$\Sigma D_n^{34} = 0$
$\Sigma D_n^{36} = 0.0005$	$\Sigma D_n^{36} = 0$	$\Sigma D_n^{36} = 0$	$\Sigma D_n^{36} = 0$	$\Sigma D_n^{36} = 0$
$\Sigma D_n^{38} = 0.0002$	$\Sigma D_n^{38} = 0$	$\Sigma D_n^{38} = 0$	$\Sigma D_n^{38} = 0$	$\Sigma D_n^{38} = 0$
$\Sigma D_n^{40} = 0.0001$	$\Sigma D_n^{40} = 0$	$\Sigma D_n^{40} = 0$	$\Sigma D_n^{40} = 0$	$\Sigma D_n^{40} = 0$
$\Sigma D_n^{42} = 0.00005$	$\Sigma D_n^{42} = 0$	$\Sigma D_n^{42} = 0$	$\Sigma D_n^{42} = 0$	$\Sigma D_n^{42} = 0$
$\Sigma D_n^{44} = 0.00002$	$\Sigma D_n^{44} = 0$	$\Sigma D_n^{44} = 0$	$\Sigma D_n^{44} = 0$	$\Sigma D_n^{44} = 0$
$\Sigma D_n^{46} = 0.00001$	$\Sigma D_n^{46} = 0$	$\Sigma D_n^{46} = 0$	$\Sigma D_n^{46} = 0$	$\Sigma D_n^{46} = 0$
$\Sigma D_n^{48} = 0.000005$	$\Sigma D_n^{48} = 0$	$\Sigma D_n^{48} = 0$	$\Sigma D_n^{48} = 0$	$\Sigma D_n^{48} = 0$
$\Sigma D_n^{50} = 0.000002$	$\Sigma D_n^{50} = 0$	$\Sigma D_n^{50} = 0$	$\Sigma D_n^{50} = 0$	$\Sigma D_n^{50} = 0$
$\Sigma D_n^{52} = 0.000001$	$\Sigma D_n^{52} = 0$	$\Sigma D_n^{52} = 0$	$\Sigma D_n^{52} = 0$	$\Sigma D_n^{52} = 0$
$\Sigma D_n^{54} = 0.0000005$	$\Sigma D_n^{54} = 0$	$\Sigma D_n^{54} = 0$	$\Sigma D_n^{54} = 0$	$\Sigma D_n^{54} = 0$
$\Sigma D_n^{56} = 0.0000002$	$\Sigma D_n^{56} = 0$	$\Sigma D_n^{56} = 0$	$\Sigma D_n^{56} = 0$	$\Sigma D_n^{56} = 0$
$\Sigma D_n^{58} = 0.0000001$	$\Sigma D_n^{58} = 0$	$\Sigma D_n^{58} = 0$	$\Sigma D_n^{58} = 0$	$\Sigma D_n^{58} = 0$
$\Sigma D_n^{60} = 0.00000005$	$\Sigma D_n^{60} = 0$	$\Sigma D_n^{60} = 0$	$\Sigma D_n^{60} = 0$	$\Sigma D_n^{60} = 0$
$\Sigma D_n^{62} = 0.00000002$	$\Sigma D_n^{62} = 0$	$\Sigma D_n^{62} = 0$	$\Sigma D_n^{62} = 0$	$\Sigma D_n^{62} = 0$
$\Sigma D_n^{64} = 0.00000001$	$\Sigma D_n^{64} = 0$	$\Sigma D_n^{64} = 0$	$\Sigma D_n^{64} = 0$	$\Sigma D_n^{64} = 0$
$\Sigma D_n^{66} = 0.000000005$	$\Sigma D_n^{66} = 0$	$\Sigma D_n^{66} = 0$	$\Sigma D_n^{66} = 0$	$\Sigma D_n^{66} = 0$
$\Sigma D_n^{68} = 0.000000002$	$\Sigma D_n^{68} = 0$	$\Sigma D_n^{68} = 0$	$\Sigma D_n^{68} = 0$	$\Sigma D_n^{68} = 0$
$\Sigma D_n^{70} = 0.000000001$	$\Sigma D_n^{70} = 0$	$\Sigma D_n^{70} = 0$	$\Sigma D_n^{70} = 0$	$\Sigma D_n^{70} = 0$
$\Sigma D_n^{72} = 0.0000000005$	$\Sigma D_n^{72} = 0$	$\Sigma D_n^{72} = 0$	$\Sigma D_n^{72} = 0$	$\Sigma D_n^{72} = 0$
$\Sigma D_n^{74} = 0.0000000002$	$\Sigma D_n^{74} = 0$	$\Sigma D_n^{74} = 0$	$\Sigma D_n^{74} = 0$	$\Sigma D_n^{74} = 0$
$\Sigma D_n^{76} = 0.0000000001$	$\Sigma D_n^{76} = 0$	$\Sigma D_n^{76} = 0$	$\Sigma D_n^{76} = 0$	$\Sigma D_n^{76} = 0$
$\Sigma D_n^{78} = 0.00000000005$	$\Sigma D_n^{78} = 0$	$\Sigma D_n^{78} = 0$	$\Sigma D_n^{78} = 0$	$\Sigma D_n^{78} = 0$
$\Sigma D_n^{80} = 0.00000000002$	$\Sigma D_n^{80} = 0$	$\Sigma D_n^{80} = 0$	$\Sigma D_n^{80} = 0$	$\Sigma D_n^{80} = 0$
$\Sigma D_n^{82} = 0.00000000001$	$\Sigma D_n^{82} = 0$	$\Sigma D_n^{82} = 0$	$\Sigma D_n^{82} = 0$	$\Sigma D_n^{82} = 0$
$\Sigma D_n^{84} = 0.000000000005$	$\Sigma D_n^{84} = 0$	$\Sigma D_n^{84} = 0$	$\Sigma D_n^{84} = 0$	$\Sigma D_n^{84} = 0$
$\Sigma D_n^{86} = 0.000000000002$	$\Sigma D_n^{86} = 0$	$\Sigma D_n^{86} = 0$	$\Sigma D_n^{86} = 0$	$\Sigma D_n^{86} = 0$
$\Sigma D_n^{88} = 0.000000000001$	$\Sigma D_n^{88} = 0$	$\Sigma D_n^{88} = 0$	$\Sigma D_n^{88} = 0$	$\Sigma D_n^{88} = 0$
$\Sigma D_n^{90} = 0.0000000000005$	$\Sigma D_n^{90} = 0$	$\Sigma D_n^{90} = 0$	$\Sigma D_n^{90} = 0$	$\Sigma D_n^{90} = 0$
$\Sigma D_n^{92} = 0.0000000000002$	$\Sigma D_n^{92} = 0$	$\Sigma D_n^{92} = 0$	$\Sigma D_n^{92} = 0$	$\Sigma D_n^{92} = 0$
$\Sigma D_n^{94} = 0.0000000000001$	$\Sigma D_n^{94} = 0$	$\Sigma D_n^{94} = 0$	$\Sigma D_n^{94} = 0$	$\Sigma D_n^{94} = 0$
$\Sigma D_n^{96} = 0.00000000000005$	$\Sigma D_n^{96} = 0$	$\Sigma D_n^{96} = 0$	$\Sigma D_n^{96} = 0$	$\Sigma D_n^{96} = 0$
$\Sigma D_n^{98} = 0.00000000000002$	$\Sigma D_n^{98} = 0$	$\Sigma D_n^{98} = 0$	$\Sigma D_n^{98} = 0$	$\Sigma D_n^{98} = 0$
$\Sigma D_n^{100} = 0.00000000000001$	$\Sigma D_n^{100} = 0$	$\Sigma D_n^{100} = 0$	$\Sigma D_n^{100} = 0$	$\Sigma D_n^{100} = 0$

$$b = \frac{BF - AC}{BN - C^2} = \frac{50.3}{50} = 1.006$$

$$a = \frac{AN - CF}{BN - C^2} = \frac{250.1}{99.9} = 1.998$$

From these values of a and b we can obtain, by means of equation 7, the corrected values of D_n^2 given in the first column of table 1. The other four columns are obtained by assuming an error of $+0.01$ for D_1^2 , D_2^2 , D_3^2 and D_4^2 .

Table 1
ERRORS IN D_n^2 DUE TO ERRORS IN MEASUREMENT

Error of $+0.01$ in	D_0^2	D_1^2	D_2^2	D_3^2	D_4^2
Corrected value of D_0^2	1.006	1.004	1.002	1.000	.998
D_1^2	3.004	3.003	3.002	3.001	3.000
D_2^2	5.002	5.002	5.002	5.002	5.002
D_3^2	7.000	7.001	7.002	7.003	7.004
D_4^2	8.998	9.000	9.002	9.004	9.006

Examination of table 1 shows that the error in D_2^2 is always $\frac{1}{5}$ the error in any one line while the error in D_0^2 or D_1^2 is larger if D_0^2 or D_1^2 is in error. Now since the two inner rings are broader than the rest it is more difficult to measure their diameters accurately. Thus the probable errors in the measured values of D_0^2 and D_1^2 would be larger than for D_2^2 . Hence the probable errors in the corrected values would be

$$b = \frac{AF - AC}{BN - CS} = \frac{50.5}{50} = 1.01$$

$$a = \frac{AN - CP}{BN - CS} = \frac{980.1}{98.9} = 1.998$$

From these values of a and b we can obtain, by means of equation 7, the corrected values of D_0^S given in the first column of table I. The other four columns are obtained by assuming an error of +.01 for D_1^S, D_2^S, D_3^S and D_4^S .

Table I
ERRORS IN D_0^S DUE TO ERRORS IN MEASUREMENT

Corrected value of D_0^S	Error of +.01 in D_1^S	D_0^S	D_1^S	D_2^S	D_3^S	D_4^S
1.000	1.000	1.004	1.008	1.012	1.016	1.020
2.000	2.001	2.003	2.005	2.007	2.009	2.011
3.000	3.002	3.004	3.006	3.008	3.010	3.012
4.000	4.003	4.005	4.007	4.009	4.011	4.013
5.000	5.004	5.006	5.008	5.010	5.012	5.014
6.000	6.005	6.007	6.009	6.011	6.013	6.015
7.000	7.006	7.008	7.010	7.012	7.014	7.016
8.000	8.007	8.009	8.011	8.013	8.015	8.017

Examination of table I shows that the error in D_0^S is always $\frac{1}{2}$ the error in any one line while the error in D_0^S or D_1^S is larger if D_0^S or D_1^S is in error. Now since the two inner rings are broader than the rest it is more difficult to measure their diameters accurately. Thus the probable errors in the measured values of D_0^S and D_1^S would be larger than for D_2^S, D_3^S and D_4^S . Hence the probable errors in the corrected values would be

Table 2
Arrangement of Data

Iron Standards

Plate 13A

Ring	Red lower		Red upper		D	D_n^2	$n D_n^2$
	Left	Right	Left	Right	$\begin{cases} \text{Red upper} \\ \text{Red lower} \end{cases}$		
	<u>4918.999</u> ⁰						
4 (weak)	2.198 202 198 200 <u>2.200</u>	4.829 26 28 29 <u>4.828</u>	2.542 40 42 43 <u>2.542</u>	5.172 73 72 71 <u>5.172</u>	2.630 <u>2.628</u> 2.629	6.907	20.721
3	2.439 40 35 37 <u>2.438</u>	4.610 12 10 13 <u>4.611</u>	2.762 60 58 58 <u>2.760</u>	4.939 39 43 44 <u>4.941</u>	2.181 <u>2.173</u> 2.177	4.739	9.478
2	2.726 25 31 28 <u>2.728</u>	4.340 36 41 38 <u>4.339</u>	3.033 35 41 37 <u>3.037</u>	4.654 53 51 50 <u>4.652</u>	1.615 <u>1.611</u> 1.613	2.583	<u>2.583</u> 32.782 = A 4 = N 131.128 = AN 88.350 = CF 42.778 = AN - CF
1 (broad)	3.167 75 82 69 73 72 <u>3.173</u>	3.887 94 88 75 64 75 <u>3.881</u>	3.494 500 501 493 497 503 <u>3.498</u>	4.195 206 197 187 191 208 <u>4.197</u>	.699 <u>.708</u> .704	.496 <u>14.725</u> = F 14 = B 206.150 = BF 196.692 = AC 9.458 = BF - AC	
					$a = \frac{42.778}{20} = 2.1389$		
					$b = \frac{9.458}{20} = .4729$		

Table 2
Arrangement of Data

Plate 13A

Iron Standards

Ring	Red lower		Red upper		D ₀	D ₀ x D ₀
	Left	Right	Left	Right		
4 (bars)	2108	2108	2172	2172	2.630	20.721
	202	202	23	23	2.632	
	188	188	23	23	2.629	
	202	202	23	23		
3	2438	2438	2782	2782	3.181	4.428
	23	23	23	23	2.102	
	23	23	23	23	2.177	
	23	23	23	23		
2	2726	2726	3032	3032	1.612	5.282
	23	23	23	23	1.611	
	23	23	23	23	1.613	
	23	23	23	23		
1 (bars)	2107	2107	2444	2444	2.627	45.228
	23	23	202	202	2.627	
	23	23	202	202	2.627	
	23	23	202	202	2.627	
<p>Σ 2108.000 Σ 202.000 Σ 188.000 Σ 202.000 Σ 2438.000 Σ 23.000 Σ 23.000 Σ 23.000 Σ 2726.000 Σ 23.000 Σ 23.000 Σ 23.000 Σ 3032.000 Σ 23.000 Σ 23.000 Σ 23.000 Σ 2107.000 Σ 23.000 Σ 202.000 Σ 202.000 Σ 202.000 Σ 2444.000 Σ 202.000 Σ 202.000 Σ 202.000 Σ 2107.000 Σ 23.000 Σ 202.000 Σ 202.000 Σ 202.000</p>						
<p>5 - 2.627 4 - 2.627</p>						

Table 3

Calculation of $2t$

Iron Standards

Plate 13

Standard λ	a	b	$\frac{\lambda}{a}$ (K λ)	$\frac{(2292.7)}{\lambda}$ corrected	$\frac{(b+2a)}{D_2^2}$ corrected	$\frac{(D_2^2 - 2)}{a}$ E	$\frac{2t \text{ (approx)}}{\lambda}$ P	$2t$
4918.999	2.1389	.4729	2299.7	.46609	4.7507	.214	37740.2	18.564408
5012.071	2.1870	.9143	2291.7	.45743	5.2883	.419	37039.4	20
5167.491	2.2565	.9310	2290.0	.44367	5.4440	.415	35925.4	26
5328.534	2.3341	1.4666	2282.9	.43026	6.1348	.640	34839.6	21
5371.493	2.3482	.0205	2287.4	.42682	4.7169	.013	34561.0	24
5405.778	2.3617	1.9222	2288.9	.42412	6.6456	.819	34341.8	25
5429.699	2.3848	1.2158	2276.7	.42225	5.9854	.527	34190.5	27
5455.613	2.3842	.2965	2288.2	.42024	5.0649	.128	34028.1	30
5572.849	2.3960	.6073	2325.8	.41140	5.3993	.221	33312.2	398
5586.763	2.4259	.6969	2302.9	.41038	5.5487	.277	33229.2	409
5615.652	2.4575	.8270	2285.1	.40826	5.7420	.344	33058.3	16
			2292.7					18.564418

larger. In the case of D_2^2 the error would be $\frac{1}{5}$ the algebraic sum of the errors of all the rings if there are five rings measured. Beyond the third ring on many lines the rings are faint and difficult to measure. Thus it seems that a corrected value of D_2^2 would be the best to use in obtaining the ϵ for each line. ϵ may be calculated from equation $8 \frac{D_2^2}{a} = 2 + \epsilon$

Plates 16, 17, and 18 were recalculated using this method. The work involved in calculating a and b by this method was not as tedious as might appear. Since four rings ($N = 4$) were measured in each case $BN - C^2$ was the same for all lines

$$B = 1^2 + 2^2 + 3^2 = 14$$

$$C = 1 + 2 + 3 = 6$$

$$BN - C^2 = 20$$

The results obtained on these three plates by this method were in such good agreement that plates 12, 13 and 14 were remeasured so that this method could also be used with them.

Table 2 shows how the data were arranged and part of the calculations made for one iron line of plate 13.

Table 3 shows how the remainder of the calculations for obtaining $2t$ were recorded.

ϵ for each hydrogen line was calculated just as for each iron line, using a corrected value of D_2^2 and the corrected slope obtained from the iron standards. Table 4 shows the results obtained from plate 13.

larger. In the case of D_0^2 the error would be $\frac{1}{2}$ the algebraic sum of the errors of all the rings if there are five rings measured. Beyond the third ring on many lines the rings are faint and difficult to measure. Thus it seems that a corrected value of D_0^2 would be the best to use in obtaining ϵ for each line. ϵ may be calculated from equation $\epsilon = \frac{D_0^2}{\lambda} = \epsilon + \epsilon$. Plates 10, 11, and 12 were recalculated using this method. The work involved in calculating ϵ and ϵ by this method was not as tedious as might appear. Since four rings ($N = 4$) were measured in each case $BW - C^2$ was the same for all lines

$$B = 1^2 + 2^2 + 3^2 = 14$$

$$C = 1 + 2 + 3 = 6$$

$$BW - C^2 = 20$$

The results obtained on these three plates by this method were in such good agreement that plates 12, 13 and 14 were remeasured so that this method could also be used with them. Table 2 shows how the data were arranged and part of the calculations made for one iron line of plate 12. Table 3 shows how the remainder of the calculations for obtaining ϵ were recorded. ϵ for each hydrogen line was calculated just as for each iron line, using a corrected value of D_0^2 and the corrected slope obtained from the iron standards. Table 4 shows the results obtained from plate 12.

Table 4
Hydrogen - Tabulation of Results - Plate 13

Approx. λ (Gale, Monk and Lee)	a	b	$\frac{2292.7}{\lambda}$ $\frac{1}{a}$ corrected	D_2^2 corrected	$(\frac{D_2^2}{2} - 2)$ E	$\frac{2t}{\lambda}$ (approx) P	($2t = 18.564418$) λ
4934.241	2.1365	1.4470	.46465	5.7200	.657	37623.7	4934.2408
4973.310	2.1467	.2135	.46100	4.5069	.078	37328.1	4973.3121
5013.036	2.1723	.7014	.45734	5.0460	.308	37032.3	5013.0330
5030.367	2.1972	1.5477	.45577	5.9421	.708	36904.7	5030.3658
5039.821	2.1818	.9302	.45491	5.2938	.408	36835.5	5039.8298
5055.091	2.1935	.4254	.45354	4.8124	.183	36724.2	5055.0936
5113.126	2.2269	.8394	.44839	5.2932	.373	36307.4	5113.1263
5146.340	2.2450	.1435	.44550	4.6335	.064	36073.1	5146.3381
5196.375	2.2629	1.6609	.44121	6.1867	.730	35725.8	5196.3720
5256.610	2.2872	.7497	.43615	5.3241	.322	35316.3	5256.6114
5303.104	2.3088	1.6902	.43233	6.3078	.727	35006.7	5303.1002
5355.912	2.3237	1.2767	.42806	5.9241	.536	34661.6	5355.9133
5388.166	2.3352	.2395	.42550	4.9099	.089	34454.1	5388.1611
5419.893	2.3453	.9454	.42301	5.6360	.384	34252.4	5419.8908
5481.083	2.3739	.0435	.41829	4.7913	.004	33870.0	5481.0794
5505.522	2.3963	1.6829	.41643	6.4755	.697	33719.6	5505.5116
5537.466	2.3929	.4035	.41403	5.1893	.149	33525.1	5537.4603
5597.636	2.4381	1.8290	.40958	6.7052	.746	33164.8	5597.6362
5612.541	2.4350	1.6032	.40849	6.4732	.644	33076.7	5612.5459
5655.750	2.4913	2.3918	.40537	7.3744	.989	32823.9	5655.7472
5728.552	2.4834	2.1764	.40022	7.1432	.859	32406.8	5728.5460
5775.050	2.5135	2.3945	.39700	7.4215	.946	32145.9	5775.0418
5806.099	2.5101	.0815	.39487	5.1017	.015	31974.0	5806.0954
5822.763	2.5255	1.3362	.39374	6.3872	.515	31882.5	5822.7584
5849.317	2.5296	2.0261	.39195	7.0853	.777	31737.8	5849.3127

Table 4
Hydrogen - Tabulation of Results - Plate 13

Approx. λ (Plate Number)	δ	ρ	$\frac{D_2}{\lambda}$ Corrected	D_2 Corrected	E $(\frac{D_2}{\lambda} - 1)$	P $\frac{D_2}{\lambda}$	Y ($\frac{D_2}{\lambda} - 1$)
4934.241	2.1262	1.4420	4934	27200	.207	37233.7	4934.2408
4973.210	2.1467	2.139	4973	47000	.078	37238.1	4973.2151
5013.036	2.1728	2.014	5013	27400	.308	37242.8	5013.0330
5052.867	2.1948	1.947	5053	27471	.508	37247.7	5052.8628
5092.701	2.2118	1.902	5093	27488	.408	37252.8	5092.7008
5132.531	2.2254	1.874	5133	27494	.183	37257.2	5132.5296
5172.358	2.2354	1.854	5173	27497	.273	37261.4	5172.3583
5212.184	2.2420	1.839	5213	27498	.064	37265.1	5212.1881
5252.009	2.2462	1.829	5253	27497	.230	37268.8	5252.0150
5291.832	2.2482	1.822	5293	27494	.322	37272.3	5291.8114
5331.654	2.2482	1.817	5333	27488	.327	37275.6	5331.6505
5371.474	2.2462	1.814	5373	27480	.236	37278.8	5371.4733
5411.292	2.2422	1.812	5413	27470	.089	37281.1	5411.2911
5451.108	2.2362	1.811	5453	27458	.384	37282.4	5451.1008
5490.922	2.2282	1.810	5493	27444	.404	37283.0	5490.9204
5530.734	2.2182	1.809	5533	27428	.697	37283.6	5530.7318
5570.544	2.2062	1.808	5573	27410	.148	37284.1	5570.5403
5610.352	2.1922	1.807	5613	27390	.246	37284.8	5610.3525
5650.158	2.1762	1.806	5653	27368	.444	37285.7	5650.1588
5690.000	2.1582	1.805	5693	27344	.488	37286.8	5690.0025
5730.000	2.1382	1.804	5733	27318	.828	37288.8	5730.0000
5770.000	2.1162	1.803	5773	27290	.948	37290.8	5770.0000
5810.000	2.0922	1.802	5813	27260	.948	37292.8	5810.0000
5850.000	2.0662	1.801	5853	27228	.948	37294.8	5850.0000
5890.000	2.0382	1.800	5893	27194	.948	37296.8	5890.0000
5930.000	2.0082	1.799	5933	27158	.948	37298.8	5930.0000
5970.000	1.9762	1.798	5973	27120	.948	37300.8	5970.0000
6010.000	1.9422	1.797	6013	27080	.948	37302.8	6010.0000
6050.000	1.9062	1.796	6053	27038	.948	37304.8	6050.0000
6090.000	1.8682	1.795	6093	26994	.948	37306.8	6090.0000
6130.000	1.8282	1.794	6133	26948	.948	37308.8	6130.0000
6170.000	1.7862	1.793	6173	26900	.948	37310.8	6170.0000
6210.000	1.7422	1.792	6213	26850	.948	37312.8	6210.0000
6250.000	1.6962	1.791	6253	26798	.948	37314.8	6250.0000
6290.000	1.6482	1.790	6293	26744	.948	37316.8	6290.0000
6330.000	1.5982	1.789	6333	26688	.948	37318.8	6330.0000
6370.000	1.5462	1.788	6373	26630	.948	37320.8	6370.0000
6410.000	1.4922	1.787	6413	26570	.948	37322.8	6410.0000
6450.000	1.4362	1.786	6453	26508	.948	37324.8	6450.0000
6490.000	1.3782	1.785	6493	26444	.948	37326.8	6490.0000
6530.000	1.3182	1.784	6533	26378	.948	37328.8	6530.0000
6570.000	1.2562	1.783	6573	26310	.948	37330.8	6570.0000
6610.000	1.1922	1.782	6613	26240	.948	37332.8	6610.0000
6650.000	1.1262	1.781	6653	26168	.948	37334.8	6650.0000
6690.000	1.0582	1.780	6693	26094	.948	37336.8	6690.0000
6730.000	0.9882	1.779	6733	26018	.948	37338.8	6730.0000
6770.000	0.9162	1.778	6773	25940	.948	37340.8	6770.0000
6810.000	0.8422	1.777	6813	25860	.948	37342.8	6810.0000
6850.000	0.7662	1.776	6853	25778	.948	37344.8	6850.0000
6890.000	0.6882	1.775	6893	25694	.948	37346.8	6890.0000
6930.000	0.6082	1.774	6933	25608	.948	37348.8	6930.0000
6970.000	0.5262	1.773	6973	25520	.948	37350.8	6970.0000
7010.000	0.4422	1.772	7013	25430	.948	37352.8	7010.0000
7050.000	0.3562	1.771	7053	25338	.948	37354.8	7050.0000
7090.000	0.2682	1.770	7093	25244	.948	37356.8	7090.0000
7130.000	0.1782	1.769	7133	25148	.948	37358.8	7130.0000
7170.000	0.0862	1.768	7173	25050	.948	37360.8	7170.0000
7210.000	0.0000	1.767	7213	24950	.948	37362.8	7210.0000

Table 5

Since the exact values of the wave lengths of the hydrogen lines are unknown the only way to judge the various methods of calculating them seems to be by comparing results obtained from several plates. If they check with small deviations and small probable errors the results must be considered good. The writer found that the final method of least squares as described above gave the smallest deviations and the smallest probable errors of all the methods tried.

RESULTS

The results obtained from all six plates are shown in table 5. The intensity of each line as listed is the mean intensity for all six plates. A line of average intensity is indicated by 0, 0₄ indicating the weakest and 5 the strongest lines on the plate.

The spread, average deviation and probable error are shown in the last three columns. The writer feels that the probable error as calculated in the usual manner does not mean much where there are only six determinations to average. The actual probability of error must be arrived at by a consideration of the spread and the deviation from the mean. The maximum spread was .0032 Å. and the mean spread was .0021 Å. About one half of the mean spread would seem to be a conservative estimate of the actual probability of error. The writer will state that he feels his values are correct to within $\pm .001$ Å. This is much larger than the calculated probable error which is .0002 Å.

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Table 5
Correlation of Results

Plate #12	#13	#14	#16	#17	#18	Mean	Spread $\times 10^3$	a.d. $\times 10^3$	P.E. $\times 10^3$	Intensity	Mean Wavelength
.2417	.2408	.2416	.2402	.2395	.2410	.2408	2.2	.6	.2	2	4934.241
.3124	.3121	.3131	.3128	.3149	.3135	.3131	2.8	.7	.2	0	4973.313
.0325	.0330	.0330	.0312	.0331	.0318	.0324	1.9	.6	.2	1	5013.032
.3652	.3658	.3672	.3650	.3666	.3668	.3661	2.2	.8	.3	0	5030.366
.8293	.8298	.8281	.8287	.8290	.8285	.8289	1.7	.5	.2	0	5039.829
.0936	.0936	.0939	.0947	.0944	.0944	.0941	1.1	.4	.1	0	5055.094
.1280	.1263	.1266	.1268	.1267	.1279	.1271	1.7	.6	.2	0	5113.127
.3387	.3381	.3392	.3385	.3382	.3377	.3384	1.5	.4	.1	0 ₂	5146.338
.3717	.3720	.3713	.3698	.3709	.3711	.3711	2.2	.5	.2	0 ₁	5196.371
.6111	.6114	.6115	.6112	.6120	.6124	.6116	1.3	.4	.1	0 ₁	5256.612
.1008	.1002	.0999	.0991	.0988	.0999	.0998	2.0	.6	.2	1	5303.100
.9126	.9133	.9112	.9116	.9114	.9137	.9123	2.4	.9	.3	0 ₁	5355.912
.1604	.1611	.1615	.1629	.1609	.1606	.1612	2.5	.6	.2	1	5388.161
.8905	.8908	.8918	.8923	.8907	.8925	.8914	2.0	.8	.3	2	5419.891
.0800	.0794	.0803	.0799	.0798	.0806	.0800	1.2	.3	.1	0	5481.080
.5112	.5116	.5123	.5091	.5106	.5113	.5110	3.2	.8	.3	0	5505.511
.4615	.4603	.4605	.4605	.4608	.4617	.4609	1.4	.5	.2	2	5537.461
.6347	.6362	.6367	.6344	.6361	.6368	.6358	2.4	.8	.3	0	5597.636
.5461	.5459	.5450	.5429	.5446	.5439	.5447	3.2	.9	.3	0	5612.545
.7456	.7472	.7460	.7473	.7478	.7464	.7467	2.2	.7	.2	0	5655.747
.5458	.5460	.5475	.5459	.5446	.5473	.5462	2.9	.8	.3	2	5728.546
.0424	.0418	.0435	.0439	.0420	.0421	.0426	1.7	.7	.2	3	5775.043
.0938	.0954	.0961	.0955	.0966	.0947	.0954	2.8	.7	.2	2	5806.095
.7592	.7584	.7594	.7595	.7568	.7578	.7585	2.7	.8	.3	2	5822.759
.3117	.3127	.3129		.3113	.3124	.3122	1.6	.6	.2	1	5849.312
						Mean	2.1	.6	.2		

but other factors must be taken into consideration. One is the possibility of systematic errors. Something in the set up of the apparatus may make all the values high or low. Also the writer feels that there is some doubt as to the accuracy of some of the iron standards recommended by the International Astronomical Union⁴. For certain iron standards the calculated values of $2t$ were always lower than the average. This would seem to cast some doubt on the correctness of those standards. For example, if four iron standards which consistently gave low values for $2t$ were omitted and the calculation based on the other seven iron standards alone, the results would be increased by about .00002%. This would mean an increase of .001 ⁰Au. for each wave length.

Thus when all the sources of error are considered the probable error of $\pm .001$ ⁰Au. seems reasonable and as small as can be claimed. In spite of this rather large probable error the writer feels that these results are good when compared with any previous ones that he has seen.

In conclusion the writer wishes to express his thanks to all who have assisted him in this work. In particular he wishes to thank Professor Norton A. Kent who directed the work, Professor Royal M. Frye who made many helpful suggestions including the least squares method of calculation, Dr. Reginald G. Lacount who assisted in the arrangement and alignment of the apparatus and Mr. Royal C. Bryant who assisted in taking the

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Thus when all the sources of error are considered the probable error of $\pm .001$ Å seems reasonable and as small as can be claimed. In spite of this rather large probable error the writer feels that these results are good when compared with any previous ones that he has seen.

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first plates during the summer of 1937.

A Fabry-Pérot interferometer (etalon) covered with a plane reflection grating in a Littrow mounting¹ was used to obtain six interferometer plates of the molecular spectrum of hydrogen between $\lambda = 4900 \text{ \AA}$. and $\lambda = 5900 \text{ \AA}$. A standard Pfund arc was used to obtain secondary iron standards on each plate.

Eleven lines in the iron spectrum recommended as standards by the International Astronomical Union² and twenty-five hydrogen lines were selected to be measured. The diameters of the interference rings of these lines were measured on a Gaertner comparator, four or five rings being measured on each line.

Several methods of calculating wave lengths were tried and a least squares method gave the best results. With this method the following relations, developed from the theory of the etalon were used:

$$p\lambda = 2t \quad (1)$$

$$p = P + \epsilon \quad (2)$$

$$p + \epsilon = K D_{\theta}^2 \quad (3)$$

$$K = \text{the plate constant} \quad (4)$$

where t = distance between reflecting surfaces of the etalon

λ = wave length

1. E.A. Kent and R.G. LaCour, A Spring Suspended Thermostated Littrow Spectrograph, Jour. Opt. Soc. Am. 10, 7, 1923

2. Transactions of the International Astronomical Union III, 56, 1928

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ABSTRACT

A Fabry-Perot interferometer (etalon) crossed with a plane reflection grating in a Littrow mounting¹ was used to obtain six interferometer plates of the molecular spectrum of hydrogen between $\lambda = 4900 \text{ \AA}$. and $\lambda = 5900 \text{ \AA}$. A standard Pfund arc was used to obtain secondary iron standards on each plate.

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1. N.A.Kent and R.G.Lacount A Spring Suspended Thermostated Littrow Spectrograph. Jour. Opt. Soc. Am. 28,7,1938
 2. Transactions of the International Astronomical Union III,86,1928

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Eleven lines in the iron spectrum recommended as standards by the International Astronomical Union² and twenty-five hydrogen lines were selected to be measured. The diameters of the interference rings of these lines were measured on a Gartinier comparator, four or five rings being measured on each line.

Several methods of calculating wave lengths were tried and a least squares method gave the best results. With this method the following relations, developed from the theory of the etalon were used:

- (1) $2t = n\lambda$
- (2) $p = F + \epsilon$
- (3) $n + \epsilon = K \frac{S}{n}$
- (4) $K\lambda = \text{the plate constant}$

where t = distance between reflecting surfaces of the etalon
 λ = wave length

1. W. A. Kent and R. G. Bacon, A Spring Suspended Thoriated Littrow Spectrograph, Jour. Opt. Soc. Am., 23, V, 1935
 2. Transactions of the International Astronomical Union, III, 26, 1938

p = order of interference at the center of the ring system

P = integral order of interference

ϵ = fractional order of interference

n = number of the ring (0, 1, 2, 3, etc)

D_n = diameter of the n th ring

K = constant for a single wave length

Referring to equation 3, if D_n^2 be plotted against n for any wave length a straight line is obtained as in figure 1 whose slope equals $\frac{1}{K}$. Then if D_n^2 be multiplied by the reciprocal of the slope, ϵ may be obtained.

The slope of this line for each iron standard was obtained by the method of least squares, and $K\lambda$ calculated. The mean value of $K\lambda$ for the eleven iron standards was used as the plate constant.

A corrected slope for each iron standard was obtained by dividing the plate constant by λ . Then ϵ was obtained by multiplying D_2^2 by $\frac{1}{\text{slope}}$ (K). This value of D_2^2 was a corrected value obtained by least squares calculation and not the square of the measured value of D_2 . D_2^2 was used because it was considered that the probable error in calculating it was less than for any other value of D_n^2 . P was obtained for each iron standard by dividing an approximate value of $2t$ by λ . Then $p = P + \epsilon$ and a corrected value of $2t$ was obtained by using equation 1. The mean value of $2t$ obtained for the eleven iron

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A corrected slope for each iron standard was obtained by dividing the plate constant by λ . Then ϵ was obtained by multiplying D_n^2 by $\frac{l}{\lambda(K)}$. This value of D_n^2 was a corrected value obtained by least squares calculation and not the square

of the measured value of D_n . D_n^2 was used because it was considered that the probable error in calculating it was less than for any other value of D_n . ϵ was obtained for each iron standard by dividing an approximate value of ϵ by λ . Then $p = \epsilon + 3$ and a corrected value of ϵ was obtained by using equation 1. The mean value of ϵ obtained for the eleven iron

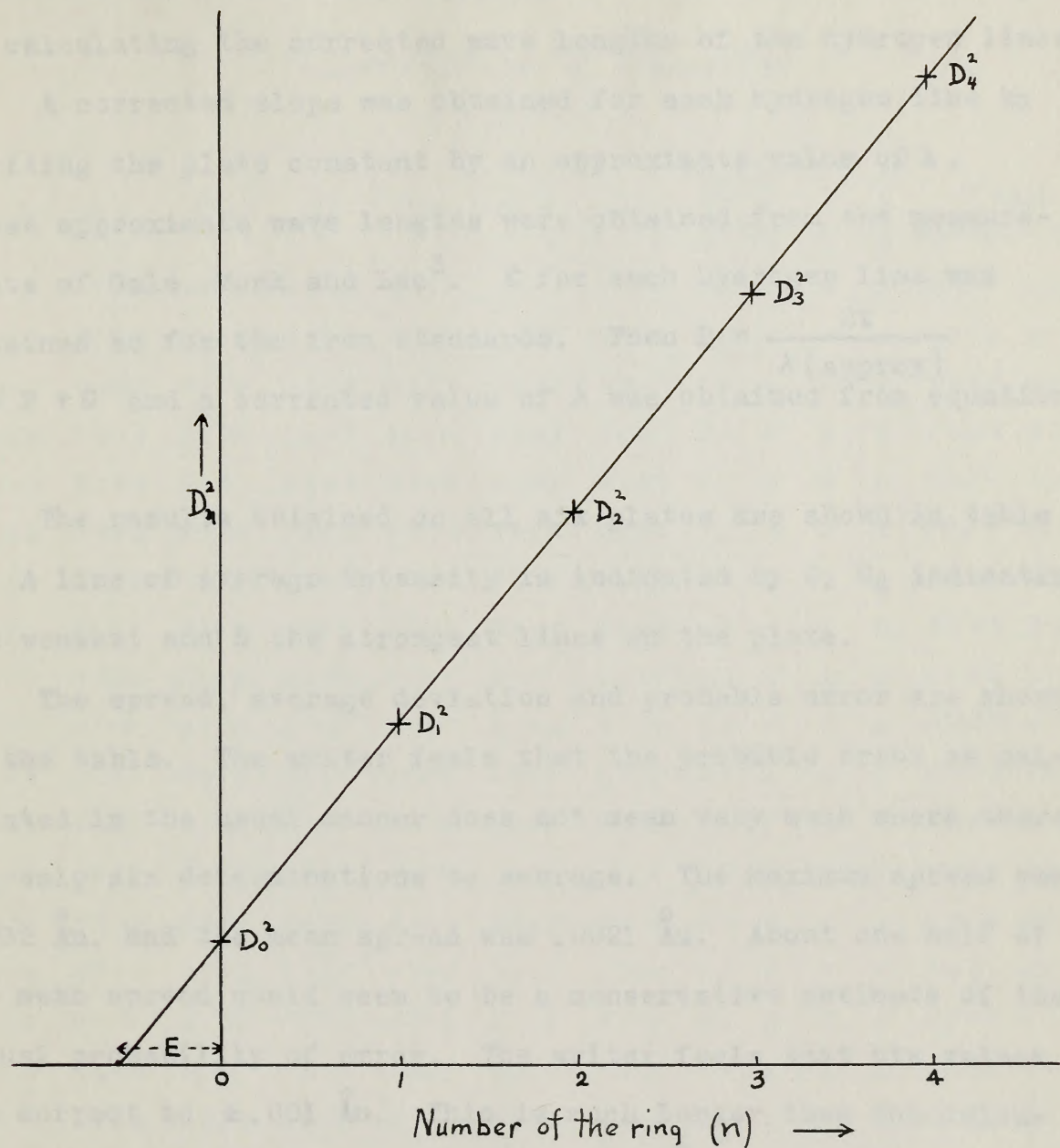
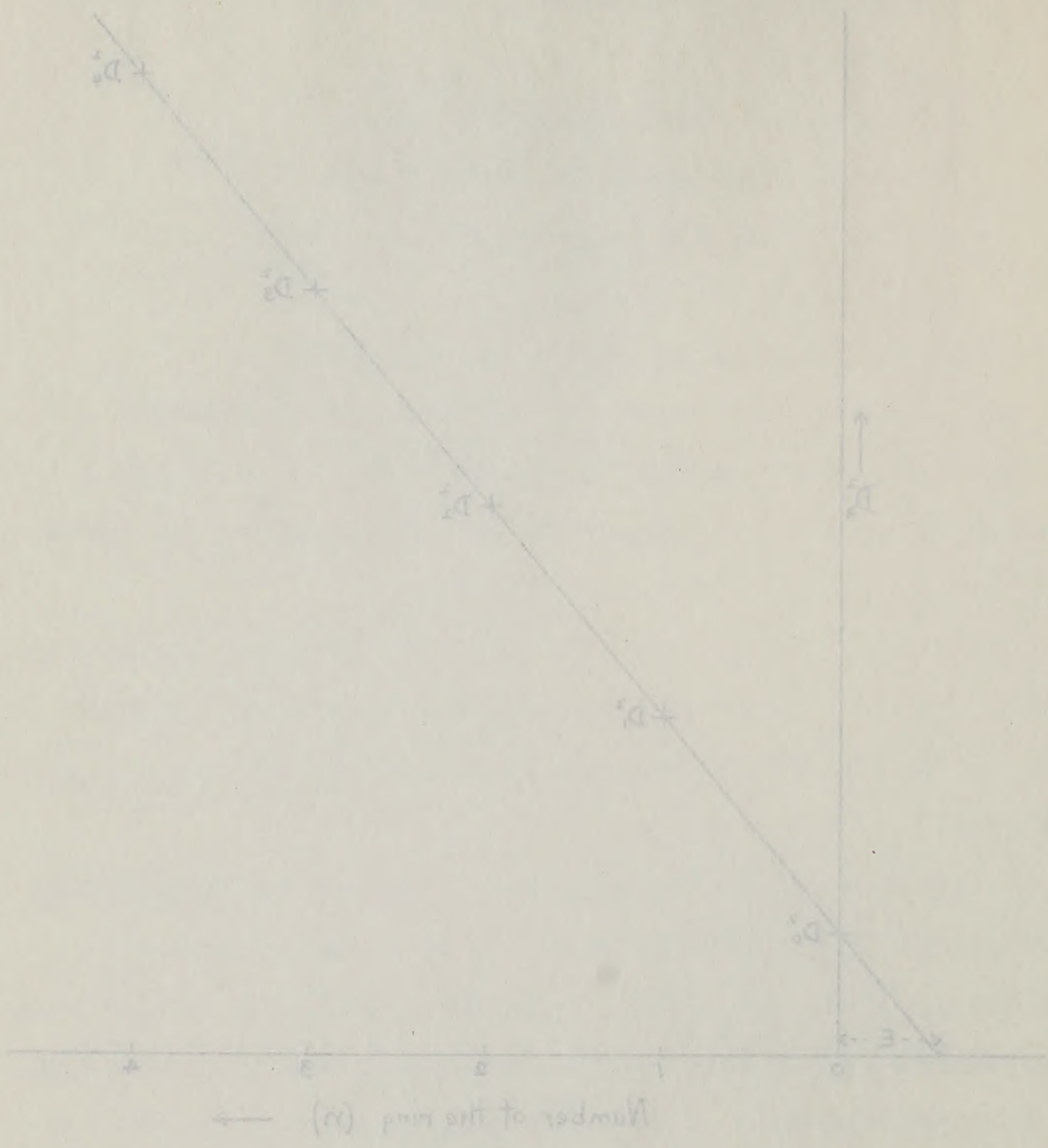


Figure 1

Graph of $KD_n^2 = n + E - D_n^2$ plotted against n



Graph of $KD_n = n + E - D_n$ plotted against n
 Figure 1

standards was calculated. This was the value of $2t$ used later in calculating the corrected wave lengths of the hydrogen lines.

A corrected slope was obtained for each hydrogen line by dividing the plate constant by an approximate value of λ . These approximate wave lengths were obtained from the measurements of Gale, Monk and Lee³. ϵ for each hydrogen line was obtained as for the iron standards. Then $P = \frac{2t}{\lambda \text{ (approx)}}$
 $p = P + \epsilon$ and a corrected value of λ was obtained from equation 1.

The results obtained on all six plates are shown in table 1. A line of average intensity is indicated by 0, 0₄ indicating the weakest and 5 the strongest lines on the plate.

The spread, average deviation and probable error are shown in the table. The writer feels that the probable error as calculated in the usual manner does not mean very much where there are only six determinations to average. The maximum spread was .0032 Å. and the mean spread was .0021 Å. About one half of the mean spread would seem to be a conservative estimate of the actual probability of error. The writer feels that his values are correct to $\pm .001$ Å. This is much larger than the calculated mean probable error which is .0002 Å. but other factors must be considered. For example there seems to be some doubt as to the accuracy of some of the iron standards recommended by

3. H.G.Gale, G.S.Monk and K.O.Lee Astrophys. Jour. 67,89,1928

standards was calculated. This was the value of λ used later in calculating the corrected wave lengths of the hydrogen lines. A corrected slope was obtained for each hydrogen line by dividing the plate constant by an approximate value of λ . These approximate wave lengths were obtained from the measurements of Gale, Monk and Lee. ϵ for each hydrogen line was obtained as for the iron standards. Then $P = \frac{\lambda}{\lambda(\text{approx})}$ and a corrected value of λ was obtained from equation $P = P + \epsilon$.

The results obtained on all six plates are shown in table I. A line of average intensity is indicated by 0.04 indicating the weakest and 5 the strongest lines on the plate. The spread, average deviation and probable error are shown in the table. The writer feels that the probable error as calculated in the usual manner does not mean very much where there are only six determinations to average. The maximum spread was 0.002 \AA and the mean spread was 0.001 \AA . About one half of the mean spread would seem to be a conservative estimate of the actual probability of error. The writer feels that his values are correct to $\pm 0.001 \text{ \AA}$. This is much larger than the labeled mean probable error which is 0.002 \AA but other factors must be considered. For example there seems to be some doubt as to the accuracy of some of the iron standards recommended by

Table 1
Correlation of Results

Argentina

Plate #12	#13	#14	#16	#17	#18	Mean	Spread $\times 10^2$	a.d. $\times 10^3$	PE. $\times 10^3$	Intensity	Mean Wavelength
.2417	.2408	.2416	.2402	.2395	.2410	.2408	2.2	.6	.2	2	4934.241
.3124	.3121	.3131	.3128	.3149	.3135	.3131	2.8	.7	.2	0	4973.313
.0325	.0330	.0330	.0312	.0331	.0318	.0324	1.9	.6	.2	1	5013.032
.3652	.3658	.3672	.3650	.3666	.3668	.3661	2.2	.8	.3	0	5030.366
.8293	.8298	.8281	.8287	.8290	.8285	.8289	1.7	.5	.2	0	5039.829
.0936	.0936	.0939	.0947	.0944	.0944	.0941	1.1	.4	.1	0	5055.094
.1280	.1263	.1266	.1268	.1267	.1279	.1271	1.7	.6	.2	0	5113.127
.3387	.3381	.3392	.3385	.3382	.3377	.3384	1.5	.4	.1	0 ₂	5146.338
.3717	.3720	.3713	.3698	.3709	.3711	.3711	2.2	.5	.2	0 ₁	5196.371
.6111	.6114	.6115	.6112	.6120	.6124	.6116	1.3	.4	.1	0 ₁	5256.612
.1008	.1002	.0999	.0991	.0988	.0999	.0998	2.0	.6	.2	1	5303.100
.9126	.9133	.9112	.9116	.9114	.9137	.9123	2.4	.9	.3	0 ₁	5355.912
.1604	.1611	.1615	.1629	.1609	.1606	.1612	2.5	.6	.2	1	5388.161
.8905	.8908	.8918	.8923	.8907	.8925	.8914	2.0	.8	.3	2	5419.891
.0800	.0794	.0803	.0799	.0798	.0806	.0800	1.2	.3	.1	0	5481.080
.5112	.5116	.5123	.5091	.5106	.5113	.5110	3.2	.8	.3	0	5505.511
.4615	.4603	.4605	.4605	.4608	.4617	.4609	1.4	.5	.2	2	5537.461
.6347	.6362	.6367	.6344	.6361	.6368	.6358	2.4	.8	.3	0	5597.636
.5461	.5459	.5450	.5429	.5446	.5439	.5447	3.2	.9	.3	0	5612.545
.7456	.7472	.7460	.7473	.7478	.7464	.7467	2.2	.7	.2	0	5655.747
.5458	.5460	.5475	.5459	.5446	.5473	.5462	2.9	.8	.3	2	5728.546
.0424	.0418	.0435	.0439	.0420	.0421	.0426	1.7	.7	.2	3	5775.043
.0938	.0954	.0961	.0955	.0966	.0947	.0954	2.8	.7	.2	2	5806.095
.7592	.7584	.7594	.7595	.7568	.7578	.7585	2.7	.8	.3	2	5822.759
.3117	.3127	.3129		.3113	.3124	.3122	1.6	.6	.2	1	5849.312
						Mean	2.1	.6	.2		

the International Astronomical Union². For certain iron standards the calculated value of $2t$ was always lower than the average. If four iron standards which consistently gave low values for $2t$ were omitted and the calculations based on the other standards alone, the results would be increased by about .00002%. This would mean an increase of .001 \AA for each wave length. Hence the probable error of $\pm .001$ seems reasonable.

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and was appointed Assistant Professor of Physics in 1928.

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